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Acoustic and Perceptual-Cognitive Factors in the Identification of 41 Environmental Sounds

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This paper addresses acoustic and perceptual-cognitive factors that correlate with aspects of identification performance. A previous study produced causal uncertainty values and identification times for 41 sounds. Acoustic attributes of the sounds and perceptual-cognitive ratings of the sounds were correlated with the uncertainty values and identification time. In addition, the ratings were correlated with the acoustic measures. Factor analyses of the perceptual-cogni[illegible] judgments and the acoustic attributes were also performed. Cluster analyses of the sounds using the factor scores and an index of causal confusion were performed. Results showed that identification time is related to causal uncertainty, to a perceptual-cognitive factor which incorporates aspects of perceived identifiability, and to some acoustic attributes of the sounds. The cluster analyses produced a cluster of water related sounds, a cluster of impact sounds, and other clusters depending on the variables being clustered.

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Abstract

This paper addresses acoustic and perceptual-cognitive factors that correlate with aspects of identification performance. A previous study produced causal uncertainty values and identification times for 41 sounds. Acoustic attributes of the sounds and perceptual-cognitive ratings of the sounds were correlated with the uncertainty values and identification time. In addition, the ratings were correlated with the acoustic measures. Factor analyses of the perceptual-cognitive judgments and the acoustic attributes were also performed. Cluster analyses of the sounds using the factor scores and an index of causal confusion were performed. Results showed that identification time is related to causal uncertainty, to a perceptual-cognitive factor which incorporates aspects of perceived identifiability, and to some acoustic attributes of the sounds. The cluster analyses produced a cluster of water related sounds, a cluster of impact sounds, and other clusters depending on the variables being clustered.

Identifying and Perceiving Environmental Sounds

Few details are known about how we identify and perceive everyday sounds. This is surprising given the ubiquitous presence of these sounds and their important functional role. It is further surprising given that listeners have probably developed a vast amount of knowledge about the sounds. Knowledge about a sound would include knowledge of its spectral and temporal attributes, knowledge of perceptual characteristics of the sound, verbal labels for the sound, and of course, knowledge of the cause of the sound. Unfortunately, this tentative listing of what the listener knows about environmental sound is based not upon a theory of how these sounds are perceived. Such a theory does not exist, and the types of knowledge listed come from the types of research has been done on these sounds. Unfortunately, the research is scattered in its methods and its selection of stimuli. Studies that include a diversity of sounds examined from perceptual and acoustic perspectives would begin to reveal details of how everyday sounds are identified. This technical report is a study of the perceptual-cognitive judgments listeners made about a set of 41 environmental sounds and the relationship between these judgments and acoustic measures. The judgments included timed identifications and perceptual-cognitive evaluations of the sounds.

Knowledge about environmental sounds includes knowledge of spectral and temporal attributes. Much has been learned about the acoustics of everyday sounds through acoustic analysis. Analyses to date suggest that the attributes used to identify a sound are idiosyncratic to the sound. For example, the distinguishing acoustic pattern of a breaking bottle is the asynchronous impulses produced by the individual pieces bouncing after breakup of the bottle (Warren & Verbrugge, 1984). A bouncing bottle produces a series of discrete impulses that are damped in amplitude. Acoustic analysis of agriculture machinery indicated that a high band spectrum, 325-3500 Hz, was more informative to the users about engine load than a lower band, 20-200 Hz, (Talamo,1982). Repp (1987) found that spectral peaks of hand claps were related to hand configuration during the clap. Halpern, Blake, and Hillenbrand (1986) found that a scraping sound similar to a fingernail across a blackboard became less chilling as the low frequencies were filtered, suggesting that the low spectrum produced the discomfort of a chilling sound. Gaver (1986) found that impacting wood and metal objects--as well as the lengths of the objects--can be discriminated using spectral attributes. These examples demonstrate that accurate identification of a sound depends upon the presence of attributes that are specific to the production of the sound. On the other hand, Vanderveer (1979) concluded that when multiple causes produce similar effects, then identification is compromised. According to her, this condition often exists in identifying the types of objects involved in an impact.

Although acoustic analysis is important in understanding environmental sound identification, a focus on acoustic attributes alone might produce limited results. The production mechanisms of everyday sounds are vast and the subsequent acoustic attributes unconstrained by a common production mechanism as is the case with speech. Thus it is unlikely that an underlying set of acoustic features common to a variety of sounds will be found.

Listeners identify sounds with verbal labels and this has received some attention. Bartlett (1977) found that verbal labeling improves both free recall of sounds and recognition of sounds previously presented. However, the facilitative effects of labeling require consistent labeling of the sounds. The effects of consistent labeling might be due to an elimination of the effect of causal uncertainty. Consistent labeling would constrain the set of alternative causes of a sound to a single cause, eliminating uncertainty and enhancing recognition performance. Consistent with this interpretation, Lawrence (1979) found that recognition performance improved if participants were given an opportunity to review the labels they had produced previously. The review would explicitly constrain the set of alternative causes. Other studies of labeling environmental sounds have compared memory for sounds to memory for the labels of these sounds (Miller & Tanis, 1971; Paivio, Philipchalk, & Rowe, 1975). Both recognition and recall memory have been compared. Generally, recall is better for labels and there is little difference in recognition.

Finally, a few studies have asked for perceptual judgments about everyday sounds. These judgments are typically ratings of the sounds on semantic differential scales which are then factor analyzed (e.g., Bjork, 1985; Solomon, 1958; Von Bismarck, 1974). The semantic scales that have emerged from these studies include loud-soft, soft-hard, round-angular, dull-sharp, relaxed-tense, pleasant-unpleasant, interesting-dull, and compact-scattered. Some of these scales characterize the timbre perception of everyday sounds, but others may tap affective judgments. Solomon (1959a, 1959b) and Bjork (1985) have had some success in relating these judgments to acoustic attributes of the sounds.

There are limitations to the studies that have been done on everyday sound perception. Most of the studies have focused on a limited set of sounds, and none have collected acoustic, perceptual, and cognitive data to assess the role of all three in identification of everyday sounds. The data analyzed in this paper include data in all three domains, on a set of 41 sounds that include very different types of sounds in order to broaden our understanding of the perception of this type of sound. Acoustics of these sounds were analyzed, perceptual-cognitive judgments about the sounds were obtained, and identification responses were analyzed for uncertainty and accuracy.

There is special attention to the identification time of the cause of a sound and how this duration is related to the stereotypy of the sound and the probability of alternative causes for the sound. An example of alternative causation is that a "click-click" can be produced by a ball-point pen, a light switch, certain types of staplers, and a camera, to name a few alternatives. Ballas, Sliwinski, and Harding (1986) found that the log of the mean time to identify (LMIT) an everyday environmental sound was a function of the logarithm of the number of alternatives that were given as causes for the sound. This finding is similar to the Hick-Hyman law for choice-reaction time (Hick, 1952; Hyman, 1953). It raises several questions about the cognitive process involved in the consideration of alternative causes. What alternatives are considered? How are they related? Which aspects of the alternatives qualify them for consideration? An important question is how to quantify alternative causation so that its effect on performance can be determined. Ballas and Sliwinski (1986) used the information measure H to quantify the causal uncertainty of 41 sounds. Their calculation was actually a measure of response equivocation in identifying a sound. The actual identification responses given by the listeners were sorted to determine how many different responses were given. The number of different responses was used to determine the number of alternatives and the relative frequencies of these alternatives was used to estimate the conditional probability of the alternatives. An extended discussion of this application of the information measure is given in Ballas and Sliwinski (1986).

The first experiment in Ballas and Sliwinski (1986) was conducted to determine the causal uncertainty values and identification response times for a set of sounds. Forty-one sounds (described in Table 1 and Appendix A, with waveforms in Appendix C) were obtained from sound-effects records to represent a variety of environmental sounds but at the same time, to pose both easy and difficult identification problems, were digitized, and determined to be subjectively good representations of the events causing the sound. A discrimination experiment confirmed that the sounds were discriminable from each other. In this study, two listeners heard each of the 820 combinations of the 41 sounds in an ABX paradigm. The order for each combination was determined randomly, and the combinations were presented in random order. Feedback was presented. Performance was 99.8% for each listener, which was only two errors in 820 judgments. None of the combinations on which errors were made were similar for the two listeners. Both listeners reported that the errors resulted from a lapse in attention.

Ballas and Sliwinski (1986) presented the sounds at a comfortable listening level in random order to listeners who were asked to identify the sounds. The identification responses were sorted by two research assistants and a third person who was unfamiliar with the research hypothesis. This third sorter was a professional technical writer. All three individuals sorted the responses into categories of similar events. Responses that were identical, synonyms, or that described the same physical scene were binned together. These sortings were then used to compute the uncertainty statistic using the equation:

$$H_j = \sum^{n} p_{ji} \ log_2 \ p_{ji}$$

where H_j is the measure of causal uncertainty for sound j, p_{ji} is the proportion of all identification responses for sound j sorted into event category i and n is the number of categories for the identification responses to sound j. Three sets of uncertainty values were computed, one for each of the three sorters. The reliabilities of the three sorters were significant, $r_{(1\&2)} = .95$, $r_{(1\&3)} = .87$, $r_{(2\&3)} = .87$, $p < .0001$. The median uncertainty value (H_{CU}) for each sound was used in the analyses in this paper. In this paper, this measure of causal uncertainty is related to perceptual-cognitive judgments and acoustic attributes of the same sounds.

In order to evaluate the role of perceptual-cognitivejudgments in the identification of the sounds, listeners were asked to rate the sounds on perceptual and cognitive scales. The scales used in this study were derived from a review of the scales used in the timbre studies and in verbal research. Perceptual ratings of the timbre of the 41 sounds were obtained using scales taken from previous studies (e.g., Solomon, 1958; Von Bismarck, 1974; Bjork, 1985). Some of the scales that have emerged from these studies include loud-soft, soft-hard, round-angular, dull-sharp, relaxed-tense, pleasant-unpleasant, interesting-dull, and compact-scattered.. Some success has been achieved in relating the scales to acoustic attributes.

Cognitive rating scales were used to solicit the listener judgments in a manner similar to how ratings have been used to assess verbal materials on category size (Battig & Montague, 1969), goodness of example (Rosch, 1975), meaningfulness and association value (Noble, Stockwell, & Pryor, 1957), concreteness and specificity (Spreen & Schulz, 1966). Comparable data do not exist for everyday sounds even though these sounds have cognitive attributes. Some of the scales requested judgments about the perceived cause of the sound. In these, a further distinction was made between the action and the agents involved because Vanderveer (1979) found that the action of a cause was more accurately identified than the agent.

Method

Stimuli. The set of 41 sounds from Ballas & Sliwinski (1986) was used. The duration of the sounds was inaccurately reported in their report. The actual duration varied for the sounds, but was a maximum of .625 s. The sample rate in digitizing and generating the sounds was 16 kHz.

Listeners. Twenty college students were listeners in this experiment and were paid or received class credit for their participation.

Rating Scales. Twenty-two rating scales (see Appendix B) were constructed using themes that had been found to be important in previous research on environmental sound and in verbal research. Listeners were also asked to rate the identifiability of the sound, and to classify the sound in terms of Gaver's (1986) scheme which is based upon the type of mapping between a sound and its meaning. He suggests three types of mappings--symbolic, metaphorical, and nomic--and develops the implications of each type in the use of natural sound in computer interfaces.

Procedure. Participants were tested individually by interacting with a microcomputer which presented stimuli and collected responses on a standard keyboard. A trial was initiated by pressing the space bar. A sound was then played through earphones. Participants then rated the sound on each of the scales, always having the option to hear the sound again. The sounds were presented in random order. The order of the ratings was fixed. Breaks were given after the fourteenth and twenty-eighth sound to offset fatigue.

Further Analyses of Ballas & Sliwinski

Ballas & Sliwinski did not report data on identification accuracy. In an reanalysis of the data, identification accuracy was calculated for each sound taking as accurate any response that met criteria used by Vanderveer (1979). Briefly, these criteria specify a response as correct if it provided a reference to the generating event or to a class of events that would include the generating event.

Ballas and Sliwinski included only limited acoustic analyses in their report. The following acoustic parameters were computed to describe the acoustics of the sounds. It is recognized that these parameters might not describe important temporal variations in the sounds. Some of the temporal attributes would be idiosyncratic, and not be computable for the full set of sounds. This was even the case for other spectral attributes (e.g., fundamental frequency) that were considered but not used in these analyses.

Sound length. The duration of the sound.

Average magnitude. The average absolute voltage level of the sound.

Peak magnitude. The maximum voltage level of the sound.

Power. The average power of the sound in dB.

Average FFT spectrum. The FFT spectrum of the sound averaged from a moving FFT analysis of 24 ms Hanning windows, shifted at 12 ms increments. The frequency resolution of the FFT was 40.7 Hz.

Maximum spectrum magnitude. The maximum value of the average FFT spectrum, in dB units.

Maximum spectrum frequency. The frequency of the FFT spectrum component with the maximum magnitude.

Moments of the average FFT spectrum. The average spectrum was treated as a distribution, and second, third and fourth central moments of this distribution were computed (Chen, 1983). Skewness and kurtosis of this distribution were calculated from these moments.

1/3 octave band spectrum computed by filtering the sound with 1/3 octave, five-pole Butterworth bandpass digital filters, and integrating the power out of each filter. Seventeen bands with center frequencies of 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300, and 8000 Hz were used. These spectra are presented in Appendix C. Bands lower than 200 Hz were dominated by noise which was probably due to record surface noise

(Alexandrovich, 1987) and were filtered out. Results of the spectral analysis reported later were similar when a lower band (160 Hz center frequency) was included. The 1/3 octave spectra for the sounds were verified by comparing these spectra to an approximation of the 1/3 octave bands obtained by combining components of the FFT spectrum, and by transporting several of the sounds to a computer running the ILS signal processing software and analyzing the 1/3 octave spectra with this software.

Results

Principal Components Analysis of Spectra.

The 1/3 octave band spectra were analyzed with a principal components analysis to determine if fewer components might describe the spectra of these 41 signals. The variance-covariance matrix was used in this analysis to preserve spectral levels in the bands. Four factors which accounted for 85% of the variance were retained. The solution was rotated with a varimax rotation which reduced the variance explained by the first component from 32% to 29%. The factor loadings are shown in Table 2. The rotated factor pattern showed that upper bands (> 3150 Hz center frequency) load on the first factor (AF1), higher middle bands (1000 Hz to 2500 Hz center frequency) on the second (AF2), low bands (200 Hz and 315 Hz center frequency) on the third factor (AF3) and lower middle bands (400 Hz to 800 Hz center frequency) on the fourth factor (AF4). Thus the average spectrum for these sounds is described by factors representing these four frequency regions. Factor scores were obtained for use in later analyses. These factor scores especially AF1, correlated significantly with other acoustic measures of the frequency spectrum (e.g., AF1 correlated with the mean frequency $r = .66$, $p < .0001$, the second moment, $r = -.85$, $p < .0001$, the skewness, $r = -.65$, $p < .0001$, and the kurtosis, $r = .57$, $p < .0001$,of the FFT spectrum) but not with measures that are unrelated to frequency such as the power or peak magnitude.

Acoustic Factors in Identification Time, Uncertainty, and Accuracy

Only one acoustic variable correlated significantly with LMIT, the magnitude of the maximum FFT component in the spectrum ($r = -.40$, $p < .009$). Two acoustic variables correlated significantly with H_{CU}: 1) the magnitude of the maximum FFT component in the spectrum ,$r = -.33$, $p = .03$; and 2) the kurtosis of the FFT spectral distribution, $r = .37$, $p = .02$. Two acoustic variables correlated with accuracy, the kurtosis of the FFT distribution, $r = -.41$, $p < .007$, and AF2, $r = -.38$, $p < .02$. However, these spectral attributes account for little of the variance in LMIT, H_{CU}, and accuracy, and considering the number of correlations that were examined, probably represent Type I errors.

Accuracy and Identification Time

Correlation of accuracy and LMIT was significant , $r = -.72$, $p < .0001$, but less than the correlation between causal uncertainty and LMIT ,$r = .89$, $p < .0001$. The direction of this relationship is opposite to what would be expected from models of speed-accuracy tradeoff, which assume that "average correct reaction time is inversely related to error rate" (Pachella, 1974, p. 62).

Perceptual-Cognitive Ratings

The null hypothesis that the data were from a normal distribution was rejected for only one of the 23 scales, the identifiability of the sound (Shapiro-Wilk statistic $W = .94$, $p = .047$). The distribution on this scale was bimodal suggesting that the set of sounds were heard as either identifiable or not.

The nature of the 41 sounds is revealed in descriptive statistics of the ratings. The highest average rating was for clarity (3.81), and the lowest was for the number of sounds that were similar (2.51). The highest variability was for the identifiability of the sounds ($SD = .94$) and the lowest was for the necessity of hearing the sound within a sequence of sounds in order to identify it ($SD = .37$).

Significant relationships were found between perceptual-cognitive ratings and acoustic measures. Power was correlated with loudness ($r = .49$, $p < .001$), and with the ratings of hardness, of angularity, of sharpness, of tenseness, of unpleasantness and of compactness ($.33 < r < .39$, $p < .05$). The relaxed/tense rating of the sound correlated with the second moment of the spectrum ($r = -.48$, $p = .001$), with the kurtosis of the spectrum ($r = .39$, $p = .01$), with the average magnitude of the spectrum ($r = .63$, $p = .0001$), and with AF1 and AF2 representing octave bands above 1000 Hz. The highest correlation between the relaxed/tense rating and an octave band measure was with the band centered at 2500 Hz ($r = .63$, $p = .0001$). The correlations between relaxed/tense rating and octave band measures dropped off in each direction from 2500 Hz. The dull/sharp rating correlated with AF1 and AF2 ($r = .48, .51, p < .001$). Besides power, loudness correlated with duration ($r = .38, p = .01$), magnitude of the maximum spectral component ($r = .60, p = .0001$) with AF2 ($r = .60, p = .0001$), and with the octave bands that compose AF2.

Overall ratings of the ease in identifying the cause were highly correlated both with ratings assessing the *action* of the cause and with ratings assessing the *agent* of the cause. The ease of forming a mental picture of the cause was significantly and similarly correlated both with the ease in forming a mental picture of the *agent* and with the ease in forming a mental picture of the *action* ($r = .98, p < .0001$ for both correlations). The ease in describing the event with words was correlated both with ease in describing the *agent* and with ease in describing the *action* ($r = .91, p < .0001$ for both correlations).

The ratings were analyzed using a principal components analysis to determine if fewer components would account for the variability in the ratings. The ratings specific to the action and agent just discussed were not used in this analysis. Three factors which accounted for 87% of the variance in the eigenvalues were retained. The first two factors alone accounted for 80% of the variance. The unrotated solution was interpretable, and gave results similar to a rotated solution using the varimax rotation. But the rotated solution improved the interpretation of the factor loadings somewhat, and only reduced the amount of variance explained by the first factor from 39% to 37%. Factor loadings are shown in Table 3.

The first factor (PC1) is composed of ratings which are all highly correlated ($p < .0001$) with the rated identifiability of the sound. These rating scales and their correlations with identifiability include the ease with which a mental picture is formed of the sound ($r = .99$), the familiarity of the sound ($r = .96$), identifiability of the sound when presented in isolation ($r = .94$), the similarity of the sound to a mental stereotype ($r = .90$), the ease in using words to describe the sound ($r = .88$), and the clarity of the sound ($r = .88$).

The second factor (PF2) is composed of ratings of sound quality. Rating scales which load high on this factor include relaxed/tense, round/angular, dull/sharp, pleasant/unpleasant, and loudness. Two of these ratings--round/angular and loudness--correlated significantly with identifiability, but the correlations were low ($r = .31, p = .05$).

The third perceptual-cognitive factor (PF3) is composed of ratings of the number of sounds in the same category, the number of similar sounds, and the number of events which could cause the sound. Together these three ratings suggest that PC3 is a measure of sound uniqueness.

The rating scale for the number of events which could cause the sound was intended to measure causal uncertainty, but was poorly designed to achieve this purpose. Instead, it tapped the uniqueness of the sound. It was expected that this scale would relate to PC1 because of the high correlation between PC1 and H_{CU}. However, the scale loaded highly on PC3 instead of PC1 because it measures a different aspect of causal uncertainty . The scale took the following form:

How many events can you think of which could have caused this sound?

__1__	__2__	__3__	__4__	__5__
not very many				very many

Note that a listener could use either endpoint for a sound that is difficult to identify. If the sound is difficult to identify because the person is unfamiliar with the sound or there is insufficient acoustic information for identification, then a response of "not very many" would be appropriate. On the other hand, if the sound is difficult to identify because many events could produce it, then the other end of the scale would be used. Thus this scale assessed whether a sound is associated with few or many events. It correlated weakly with rated identifiability and in a direction opposite to what would be expected if the scale was confounded with identifiability ($r = .31$, $p = .05$). A second aspect of this scale deserving discussion is the use of the word "event" as a cause. This could have focused the listener's thoughts on the occassions in which the sound occurs, rather than the agents and actions that actually produce the acoustics of the sound. This, together with the meaning of the other two ratings which loaded high on PC3, would suggest that a "unique" sound is one which has few similar sounds in the same category and which rarely occurs.

Perceptual-Cognitive and Acoustic Factors in Identification

One of the most important questions in analyzing the identification of these 41 sounds is the relationship between acoustic attributes, perceptual-cognitive judgments, and the identification of the sound. Multiple regression analysis was used to find multiple correlates of identification performance such as identification time, identification accuracy, and perceived identifiability. Stepwise multiple regression was performed with the dependent variables including H_{CU}, the factor scores from the octave band measures, the factor scores from the perceptual-cognitive ratings, and other acoustic measures. With LMIT as a dependent variable, the independent variables that produced significant ($p < .05$) increments in R^2 were H_{CU} and PC1 (identifiability). The R^2 with these two independents was .85, with H_{CU} alone, R^2 is .79. No single variable correlates as highly with LMIT as H_{CU} (and only one rating, the similarity of the sound to a mental stereotype, correlates as highly with LMIT as H_{CU}).

With accuracy as a dependent variable, independent variables that produced significant increments in R^2 were H_{CU}, PC1, and the peak amplitude in the wave. R^2 with these three variables was .67. Each of the variables PC1 and peak amplitude added about 5% to R^2. When the dependent variable was the rated identifiability of the sound, the independent variables that produced significant increments in R^2 were PC1, the familiarity with the sound event (not familiarity with the sound itself, which is included in PC1), and the peak amplitude in the wave. R^2 was .97 with these independents. However, the increase in R^2 after PC1 was only 1%. Taken together with the previous results, performance measures of identification such as response time, accuracy and perceived identifiability are related to causal uncertainty--as quantified in H_{CU} values--to perceptual-cognitive judgments of the sound, and for accuracy, to the peak amplude in the wave.

Cluster Analysis of Sounds

The listing in Table 1 is sorted by increasing Hcu and a casual scan of the listing suggests that there are categories of sounds that vary in Hcu and in MRT. For example, several of the sounds that are low in Hcu and MRT are signalling sounds such as telephone, car horn, and doorbell. Furthermore, most of the water sounds such as drip, bubbling, oar rowing, and flush are in the lower half of the listing of Hcu and LMRT. This suggests two categories of sounds, signalling and water, which have similar uncertainities and identifications times within the category.

There has been virtually no research about the categories that listeners might use in perceiving everyday sound, let alone the basis for these categories. In order to investigate category structure in the 41 sounds used in this study, two types of cluster analyses of the sounds were conducted. The first analysis was intended to determine whether the perceptual and cognitive ratings of the sounds would produce interpretable clusters of the sounds. If this were the case, then the cluster structure might reflect knowledge about sounds and form the basis of the ratings. Accordingly, factor scores for PF1, PF2 and PF3 were used in a hierarchical cluster analysis.

The second analysis was designed to determine how the sounds would cluster on the basis of identification responses, and to determine whether there were sounds that might be confused as evidenced by similar identification responses. Accordingly, the hierarchical cluster analysis was based upon an index of causal similarity calculated from a confusion matrix of identification responses. The confusion matrix was based upon an analysis of the similarity of the events used to identify pairs of the sounds.

Perceptual/cognitive ratings clustering. To discover how the sounds would cluster based upon perceptual/cognitive ratings, a complete linkage cluster analysis was done with PF1, PF2, and PF3 as the clustering variables. Factor scores for these variables were used directly except for selected changes in sign to improve the interpretation of cluster plots. There were four major clusters as shown by the tree diagram in Figure 1. This tree diagram and others to follow indicates clustered components with Xs in the column beneath the sound(s) that are in the cluster. The distance between the clusters is indicated in the margin. Interpretation of the four clusters is aided by plotting the sounds in 3-D space (Figures 2-5) with the dimensions being the three variables used in the cluster analysis, *Identifiability* (PF1), sound *Quality* (PF2), and sound *Uniqueness* (PF3).

The first cluster consists mostly of sounds that are produced with water (drip, splash, bubble, flush) or in a water context (boat whistle, foghorn). Additional sounds in this cluster include the lighter and clock ticking. However, one of these, the lighter sound, is at the edge of the cluster and is the lowest of the cluster on identifiability. Most of the sounds have negative sound quality scores (i.e., ratings of soft, round, dull, relaxed and pleasant), and three sounds (lighter, flush, and foghorn) have the highest uniqueness scores of all 41 sounds. High uniqueness is related to ratings that there are few sounds in the same category, few similar sounds, and few events could be thought of which could cause the sound. These three sounds with high uniqueness scores, together with the boat whistle, form a sub-cluster. The other sub-cluster includes three water sounds and the clock tick.

The second cluster consists of several signaling sounds (telephone, doorbell, bugle, subhorn, and carhorn), and sounds that connote danger (fireworks, auto rifle, and power saw). Two of the non-signaling sounds, fireworks and powersaw, stand at the edge of the cluster and are low in identifiability compared to the rest of the sounds in the cluster. These sounds have high identifiability scores (Figure 3) and positive sound quality scores (i.e., ratings of hard, angular, sharp, tense, and unpleasant). Three sub-clusters are evident. One includes signalling sounds (doorbell, telephone ring and bugle), one includes the fireworks, subhorn, and powersaw sounds, and the third includes the autorifle and carhorn.

The third cluster includes sounds that have negative identifiability scores (Figure 4), meaning they were rated as difficult to identify. It includes several door sounds (jail door closing, door opening, electric buzzer (used on some doors to remotely open the door), and key inserted in lock), three engine sounds (car backfire, car ignition, and lawnmower), a sound that was sometimes identified as an engine sound (tree saw) and two other sounds (bacon frying and rifle shot outdoors). Within the cluster, these sounds have somewhat different acoustics and generally there is a combination of negative and positive sound quality scores, rather than a dominance by one or the other as in clusters 1 and 2. Several of the sounds have perceptible echoes such as the jail door, the outdoor rifle shot, and the car backfire. Four sub-clusters comprise this cluster, but the distances between these sub-clusters is small compared to the distance between this major cluster and the other major clusters. Thus this major cluster is the most homogeneous of the four.

The fourth cluster includes most of the non-signalling and non-water sounds that have two or more transient components (light switch, stapler, footstep, clogstep, phone hang, file cabinet, door knock, hammer, corkpop, and door close). It also includes two bell sounds, the touchtone sound, and several single transient sounds (tree chop, and rifle indoors). Most of the transient sounds in this cluster have sharp attacks and most have negative uniqueness scores but vary moderately in identifiability (Figure 5). This result is consistent with the conclusion that uniqueness is not confounded with identifiability. There are two sub-clusters within this cluster, and each sub-cluster is further divided into two clusters.

In summary, clustering of the sounds using scores on three perceptual/cognitive factors produces four clusters, identified by the majority members as follows: a water cluster, a signal sound cluster, a cluster of sounds difficult to identify, and a cluster of multiple transient sounds. At a higher level, the water and signal clusters combine, and the multiple transient and poor identifiability clusters combine, probably on the basis of identifiability scores because in general the signal and water sounds have lower Hcu values..

Identification response clustering. In identificaition research, confusion matrixes are frequently used to discover perceptual structure. Often, the goal is to discover the psychophysical dimensions that form the basis for perceptual judgments. Until now, the analysis of the 41 sounds has been based upon measures of uncertainty, identification time, acoustic parameters calculated from the sounds, and the perceptual/cognitive ratings. However, these data do not address the issue of identification confusions within the set of 41 sounds. They certainly cannot form the basis for a confusion matrix of identifications. However, identification responses can be used to produce a confusion matrix. This in turn can be used to calculate an index of identification confusion for pairs of sounds, which can serve as a distance measure in a cluster analysis. A cluster analysis of these distances would suggest the alternative choices a listener might consider in making an identification response.

In order to develop a confusion matrix, the identification responses for the 41 sounds were combined and sorted by similar response and by sound. Altogether, 1795 identification responses were sorted into categories of events using the criteria developed by Ballas and Sliwinski to sort the identification responses for a single sound. A confusion matrix was generated by counting the number of event categories that pairs of sounds had in common. Using only event categories that occurred for at least two sounds resulted in a total of 66 categories. A data matrix was formed of 66 event categories by the 41 sounds, with the entries a binary notation of the occurrence of an event category used to identify a sound. Distance between sounds was computed from this matrix as follows

$D_{ij} = 1/(e_{ij} + 1)$

D_{ij} = distance between sound i and sound j

e_{ij} = number of events cited in common for sounds i and j.

These distance data were used in a cluster analysis. Two solutions were informative, one based upon single linkage or the minimum method (tree diagram in Figure 6), and one based upon complete linkage or the maximum method (tree diagram in Figure 7). The single linkage clustering produces fewer clusters, irregular in shape whereas the complete linkage clustering produces more clusters, most of which are compact and similar in shape. In both solutions, distance between clusters will indicate identification confusion inversely. There is more confusion with smaller distances between the cluster. There are similarities in the two solutions. Both produce two large clusters of the sounds, one composed mostly of impact sounds, and the other composed of water, signalling, and continuous sounds. In both solutions, the first four clusters formed are identical. However, with some exceptions, the complete linkage algorithm continues to form cluster pairs whereas the single linkage algorithm joins sounds to the first four clusters. The single linkage solution is therefore useful in seeing the hierarchical nature of sound identification confusions, whereas the complete linkage solution is useful in finding sound pair confusions. The reason for this is based upon differences in the algorithm for the two solutions. In single linkage, distance between clusters is based upon the minimum distance between any pair of observations. Therefore, an existing cluster can pick up additional members even if it has existing members that are very different from the new addition. In complete linkage, distance is based upon the maximum distance between any pair of observations. Therefore, additional members will be compared to the most distant member of existing clusters. Clustering is biased toward the formation of paired clusters.

In the single linkage solution, the impact sound cluster is composed of three sub-clusters: 1)corkpop, tree chop, file cabinet; 2) door open, door close; and 3) door knock, hammer) The remaining impact sounds are joined to the cluster formed by these three sub-clusters. The water and signalling cluster consists of a sub-cluster of water sounds (bubble, splash, drip), and water-related sounds (flush and bacon frying, which sounds like rain) joined to this sub-cluster. This is the only sub-cluster within the water-signal cluster that has components as close as the three sub-clusters in the impact cluster. Three other sub-clusters are evident but the distances are greater, meaning that identification confusion is less. These include a cluster of signalling sounds three of which are produced by bells (telephone ring, doorbell, church bell, and touchtone), a cluster of horns (car horn, fog horn), and a cluster of two engine sounds (lawnmower-car ignition). The rest of the sounds in this major cluster are joined to these four sub-clusters.

The complete linkage solution is characterized by smaller clusters within the two major clusters. The water-signalling sub-cluster is composed of clusters of sound pairs including lighter and tree saw, subhorn and powersaw, lawnmower and car ignition, telephone ring and doorbell, touchtone and church bell, drip and splash, bubbling and bacon frying, flush and bell buoy. One sub-cluster is best characterized as a triplet of the foghorn, car horn, and bugle. Most of these pairs have similar acoustic signatures. The impact sound cluster consists of sound pairs and triplets. The pairs include hammer and door knock, door open and door close, car backfire and auto rifle. The triplets include stapler, fireworks, and rifle outdoors, and a triplet of cork pop, tree chop, and file cabinet. Other sounds are joined to the pairs or triplets. One sub-cluster that is clearly evident in the tree is the four impact sounds resulting from the inclusion of clog step and footstep to the hammer and door knock pair.

In summary, the clustering of identification responses using a causal similarity index produces clusters that clearly have similar acoustic signatures. Different clustering criteria result in similar solutions with two major clusters emerging, one including most of the impact sounds, the other the water, signalling and continuous sounds. Minor clusters consist of sounds that have similar acoustic signatures. As a whole, the set of sounds includes a number of pairs that are confused, and a small number of larger clusters of sounds that are confused.

Comparing the clustering of the sounds on perceptual/cognitive scores with the clustering on identification response similarity shows similarities at the highest level, but differences at lower levels. Overall, both clustering approaches presented groupings of water sounds and impact sounds. The factor score clustering produced solutions that revealed similarities in how the sounds are perceived, the identification response clustering revealed identification confusions. In some respects, the two clustering approaches produced inverse solutions. For example, the factor score clustering produced a cluster of sounds that are identifiable, composed mostly of signal sounds. These same sounds were not clustered in the identification response clustering until the distance between clusters was increased. Thus although signal sounds have similar perceptual properties, they are not necessarily confused in identifications, but in fact are quite identifiable. Both approaches produced a water cluster, and a cluster of impact sounds, suggesting that water sounds and impact sounds have properties that unite them in a perceptual/cognitive domain and also make them confusable sounds.

Discussion

The studies of these 41 sounds have produced the following results relevant to understanding the identification of isolated everyday sounds, subject to the limitations of the stimulus set:

1. The time to identify a brief everyday sound increases as H_{CU} increases and as the perceived identifiability of the sound decreases.

2. Perceived identifiability is related to the ease with which a mental picture is formed of the sound, the familiarity of the sound, the ease in identifying the sound in isolation, the similarity of the sound to a mental stereotype, the ease in using words to describe the sound, and the clarity of the sound. Listeners did not distinguish between their ability to imagine or describe the agent and their ability to imagine or describe the action involved in the cause of the sound.

3. Spectral acoustic variables are relatively minor factors in the time to identify a sound, in H_{CU} , and in perceived identifiability of a sound. They are related to perceptual-cognitive judgments of the sound quality. The weak relationship between H_{CU} and spectral magnitude and kurtosis should be interpreted with caution, because Ballas and Barnes (1988) found that in a different set of sounds, the average frequency in the spectral distribution was inversely related to H_{CU}.

4. Clustering of the sounds using scores on three perceptual/cognitive factors produces four clusters, a water cluster, a signal sound cluster, a cluster of sounds difficult to identify, and a cluster of multiple transient sounds. Clustering sounds on the basis of a causal similarity index produces two major clusters one including most of the impact sounds, the other water, signalling and continuous sounds. Small clusters were based upon pairs of sounds that seemed to have similar acoustic signatures, but this similarity is not captured by similarity of 1/3 octave profiles.

The results show that LMIT is estimated better with H_{CU} than by the acoustic measures computed for these sounds. However, there are well known limitations of information measures (Wickens, 1984). One of the limitations of the Hick-Hyman law is that it does not account for the effect of non-information variables (subset familiarity, stimulus discriminability, repetition effect, stimulus-response compatibility, and practice) on response time. However, the sounds were discriminable from one another based upon the ABX results, and were presented only once to the listeners in the Ballas and Sliwinski study in random order. Thus there was no opportunity for these effects to develop. If the relationship between response time and H_{CU} is due to discriminability effects, it would not be discriminability within the set of 41 sounds. Instead, the relationship would be due to the discriminability of sounds representing alternative causes for the sounds actually heard. For example, the increased time to identify the sound of a door closing, a very familiar event, could be due to response competition from reasonable, alternative causes for this sound. This sets up a classical choice response time task, where the number of choices are determined by the number of reasonable alternative causes for a sound. These alternatives were not presented to the listeners, and were not represented in the set (except for two sounds which will be discussed shortly).

It is possible that many of the perceptual-cognitive judgments, and even the measure of H_{CU} may be redundant. Clearly, there is redundancy between the rating of identifiability and many of the other ratings. These ratings simply amplify on what is meant by an identifiable sound. It is one which generates a mental picture, can be described easily with words, is similar to a stereotype, can be identified when presented in isolation, and is clear. Clarity probably refers to the lack of spectral complexity because of the significant correlations between identifiability and both the magnitude of the maximum value in the spectrum and the kurtosis of the spectral distribution.

H_{CU} might be redundant with the perceptual-cognitive judgments, because it correlates with PC1 ($r = .79$, $p < .0001$) but not with PC3 ($r = .04$, $p = .82$), which represents sound uniqueness. It is calculated from the aggregated responses of a group of listeners, is equivalent to response equivocation, and is properly considered a response measure. Thus one would expect it to be related to judgments of the ease in describing the sound with words, and forming a mental image of the sound, two components of PC1. It is also correlated with the rating of the stereotypy of the sound ($r = .85$, $p < .0001$), and in fact, this property of a sound may be the most important component in identifiability. Stereotypy would certainly be responsible for the quick identification and high identifiability ratings of synthetic signalling sounds such as the telephone ring, the doorbell, and car horn. A strong stereotype would exist for these sounds. But sounds with lower H_{CU} values also include water sounds, which cannot be restricted by design as can the synthetic sounds. Stereotypy can account for the identifiability of synthetic sounds, but can it account for the identifiability of natural sounds?

The results suggest that identification is largely based upon reference to a stereotype for the sound. A stereotype might include multiple attributes and further research could pursue the nature of the stereotype. In the absence of a strong stereotype, alternative causes must be considered. These alternatives establish alternative choices, and the inability to discriminate between these alternatives would increase identification time in the same manner that stimulus indiscriminability increases response time in a typical choice response task. On the basis of response equivocation, some sounds have few if any alternatives, others have many. The possibility (or lack thereof) of alternatives may come from the lack of a stereotype, similarity in acoustics, limitations of perception, or known variability in the sound of an event. Any account of everyday sound perception, if it is to address the perception beyond a limited domain of sounds, must address the possibility of alternative causes and how they are considered by the listener. Current research is assessing the effect of context (Ballas & Mullins, 1989)

The results of these experiments are subject to the limitations of the stimulus set used throughout the experiments. Listeners felt that the sounds were clear, varied in identifiability, and that presenting them in isolation did not diminish the identifiability. These characteristics are what one would want in a set of isolated sounds to study identification processes. But the findings for these sounds have been found with other sounds. The relationship between H_{CU} and identification time was first found with a different set of sounds (Ballas, Sliwinski, & Harding, 1976) which included animal vocalizations. The measure of H_{CU} is consistent for different exemplars of the same sound (Ballas, Dick, & Groshek, 1987) implying that the results are not limited to the particular exemplars used in these studies. Significant correlations have been found between H_{CU} and rated confidence in identifying a sound (Ballas & Howard, 1987) in two studies that used two sets of sounds different from the sounds used here. Finally, several studies have used sounds longer than the brief duration that has to be used to obtain interpretable identification response times. Results of these studies (Ballas, Dick, & Groshek, 1987; Ballas & Howard, 1987) are consistent with the general findings reported here.

Although the general relationships between performance measures (identification time, causal uncertainty, and perceived identifiability) and measures made on the 41 stimuli may generalize beyond this set of sounds. the clustering results should be generalized with caution. The clustering results show that categories of everyday sounds are related to acoustic, perceptual-cognitive, and performance variables. But the categories found in this study, especially the two major categories of impact sounds and water sounds, may be determined by the sounds in the stimulus set. For example, there were not many friction sounds such as sandpapering, tires squealing and metal grinding. Furthermore, there were no wind or storm sounds. A second issuo related to the generalization of these categories concerns the nature of the categories. They have only been defined here by a listing of members, and by relative scores on three perceptual-cognitive dimensions. Important questions remain about the external and internal structure of everyday sound categories. These include questions about taxonomic structure, internal attributes, existance and definition of prototypes, and level of description (Rosch,1978).

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Table 1

Identification Performance Measures For Test Sounds

Sound		MRT	Hcu
1.	Telephone ring	1253	0.44
2.	Clock ticking	1592	1.07
3.	Car Horn	1611	0.75
4.	Doorbell	1642	0.58
5.	Automatic rifle	1666	1.89
6.	Riverboat whistle	1751	1.26
7.	Water drip	1831	1.14
8.	Bell buoy	1912	2.81
9.	Foghorn	2135	2.24
10.	Water bubbling	2325	2.75
11.	Bugle charge	2356	2.19
12.	Rifle shot indoors	2371	2.97
13.	Lawn mower	2596	3.65
14.	Church bell	2614	2.88
15.	Oar rowing	2745	3.37
16.	Door knock	2779	1.98
17.	Toilet flush	2779	1.84
18.	Footsteps	2823	2.53
19.	Fireworks	2926	3.23
20.	Cigarette lighter	3210	3.46
21.	Touch tone dial	3305	2.84
22.	Door opening	3335	2.94
23.	Bacon frying	3422	3.42
24.	Hammering	3624	3.13
25.	Sub dive horn	3695	3.51
26.	Walking in clogs	3799	2.23
27.	Car ignition	3802	3.27
28.	Wood chop	4071	4.51
29.	Power Saw	4113	4.45
30.	Key in lock	4240	3.67
31.	Cork popping	4296	3.60
32.	File cabinet door	4305	3.34
33.	Door closing	4372	2.90
34.	Car backfire	4610	3.72
35.	Jail door closing	5197	3.96
36.	Rifleshot outdoors	5240	3.88
37.	Light switch	6022	4.40
38.	Stapler	6055	4.65
39.	Telephone hangup	6660	4.78
40.	Tree sawing	6792	4.72
41.	Electric lock	6823	4.11

Note. MRT = mean reaction time(ms); H_{UC} = Median uncertainty values for three sorters

Table 2

Factor Loadings for Four Acoustic Factors

Center Freq. (Hz)	Factor 1	Factor 2	Factor 3	Factor 4
200	.06	-.16	.92	-.06
250	.06	.17	.90	-.02
315	-.04	.03	.86	.40
400	-.15	.16	.62	.64
500	-.13	.54	.38	.60
630	.00	.07	.20	.79
800	-.03	.34	-.20	.77
1000	-.10	.74	.10	.56
1250	-.04	.82	-.18	.28
1600	.13	.63	.06	.21
2000	.49	.80	.03	-.08
2500	.56	.75	.18	.03
3150	.82	.47	.10	.02
4000	.89	.34	-.04	-.21
5000	.97	.09	.01	-.13
6300	.98	-.07	-.06	.02
8000	.95	-.06	.02	.06

Table 3

Factor Loadings for Three Perceptual-Cognitive Factors

	Factor 1	Factor 2	Factor 3
Ease in forming a mental picture	.97	.09	-.03
Isolated identifiability	.95	.01	-.06
Sound familiarity	.95	.13	-.11
Similarity to mental stereotype	.91	.20	-.10
Ease in describing sound with words	.89	-.10	-.28
Clarity	.89	.01	-.10
Interesting/boring	.78	-.19	-.00
Relaxed/tense	.05	.97	.08
Soft/hard	.02	.95	.19
Round/angular	.26	.89	.18
Dull/sharp	-.18	.87	.27
Pleasant/unpleasant	.28	.86	-.13
Loud/soft	-.39	.79	.03
Number of sounds in same category	-.15	.16	.92
Number of similar sounds	.04	.23	.86
Number of causal events	-.33	.44	.73
Compact/scattered	.14	.38	-.55

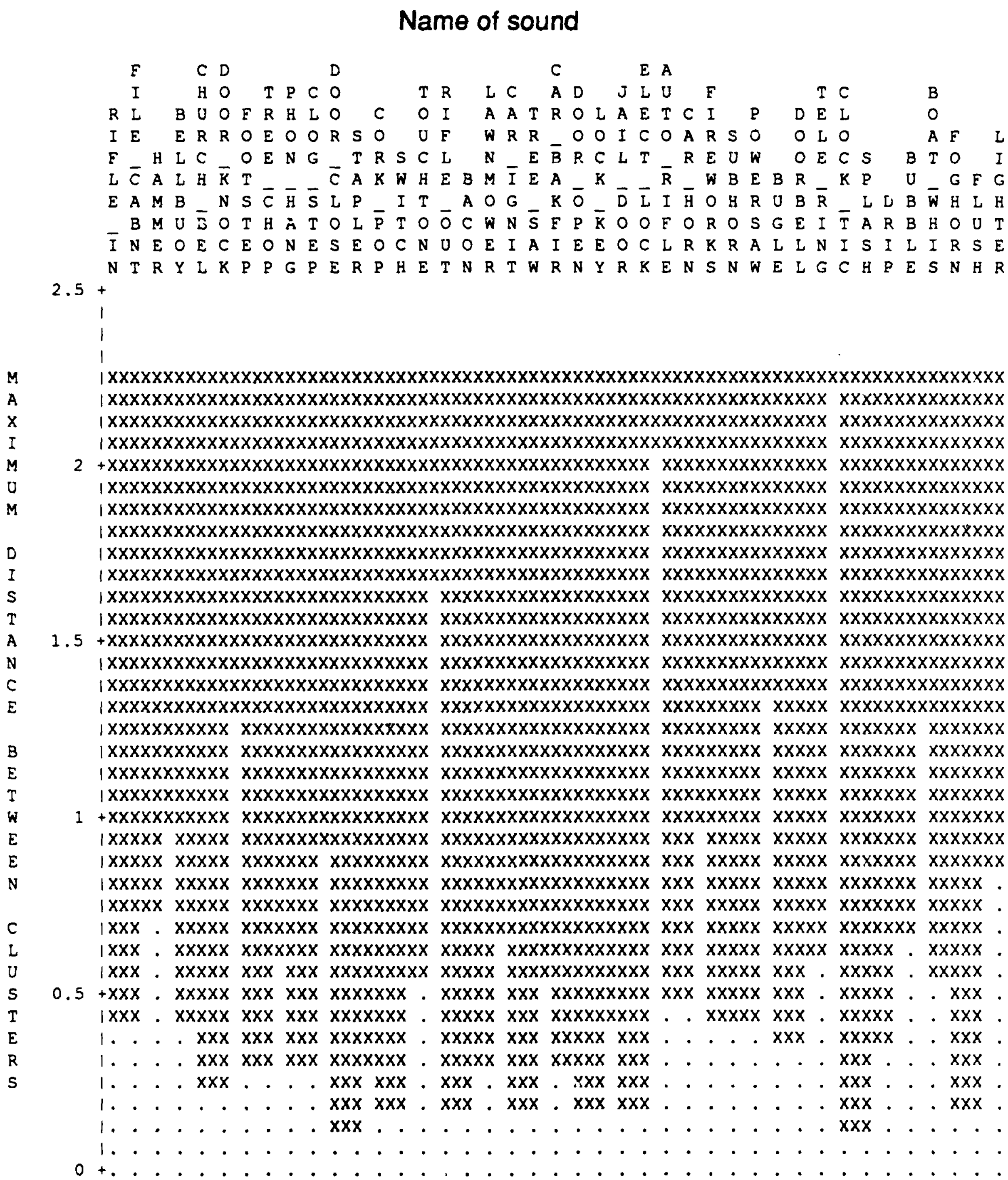


Figure 1. Complete linkage cluster analysis of PF1, PF2, and PF3.

Table 4

Factor Scores on Three Perceptual-Cognitive Factors

Sound	Identifiability	Quality	Uniqueness
1. Telephone ring	1.8051	0.3559	0.7269
2. Clock ticking	0.8643	-1.2319	-0.1267
3. Car Horn	1.7320	1.7817	-0.1631
4. Doorbell	1.8169	-0.6765	-0.0484
5. Automatic rifle	1.4772	2.3056	0.7344
6. Riverboat whistle	0.4979	-0.6232	0.8122
7. Water drip	1.1189	-1.2313	0.4162
8. Bell buoy	0.9738	0.4416	-0.7944
9. Foghorn	0.8993	-1.2254	1.5758
10. Water bubbling	0.5305	-2.5203	-0.3634
11. Bugle charge	1.8085	-0.0901	-0.6622
12. Rifle shot indoors	-0.3993	1.2374	-1.4659
13. Lawn mower	-0.2245	0.5973	0.1640
14. Church bell	0.9158	0.0325	-1.4782
15. Oar rowing	0.7036	-1.3898	-0.2945
16. Door knock	0.4689	0.3009	-1.5785
17. Toilet flush	0.6423	-1.3463	1.8883
18. Footsteps	-0.4304	-1.2338	-1.4979
19. Fireworks	0.7020	1.7191	0.7161
20. Cigarette lighter	-0.8224	-1.4921	2.0140
21. Touch tone dial	0.3142	-0.4103	-0.4945
22. Door opening	-0.9378	0.3070	0.0268
23. Bacon frying	-0.8000	0.3573	0.5866
24. Hammering	-0.1352	0.1746	-2.7178
25.Sub dive horn	0.5889	0.8699	1.0630
26. Walking in clogs	-0.7647	-0.6098	-0.1882
27. Car ignition	-1.3541	-0.2430	0.8155
28. Wood chop	-1.0564	-0.7822	-1.5734
29. Power Saw	-0.2338	1.4706	0.8750
30. Door latched	-1.1821	0.1294	0.2596
31. Cork popping	-0.4326	0.1654	0.1650
32. File cabinet door	-0.5370	0.3032	-1.1127
33. Door closing	-0.3843	0.1365	-0.4233
34. Car backfire	-1.0389	0.7162	-0.0332
35. Jail door closing	-1.0553	0.9311	0.6787
36. Rifleshot outdoors	-0.4431	0.4987	0.8053
37. Light switch	-0.7039	-0.1286	0.1627
38. Stapler	-0.5568	0.2221	-0.1979
39. Telephone hangup	-1.3521	-0.4752	-0.6108
40. Tree sawing	-1.5771	-0.0879	0.5163
41. Electric lock	-1.4382	0.7439	0.8227

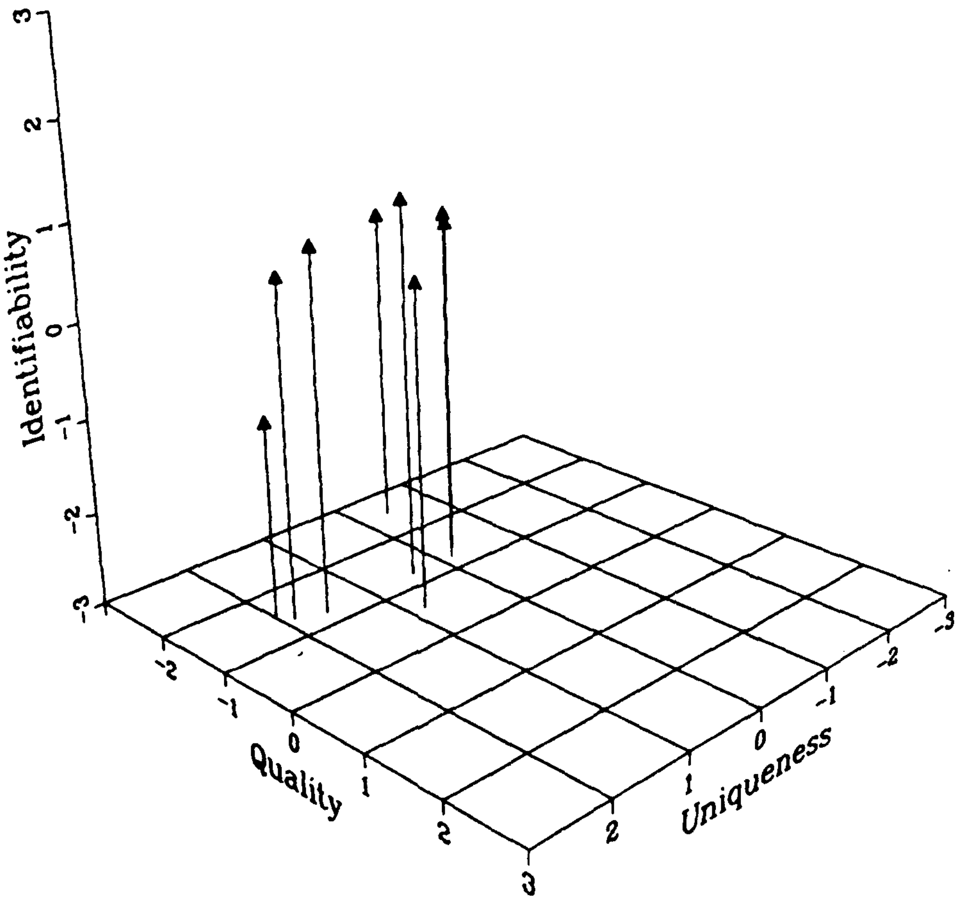


Figure 2. Cluster 1, consisting of the eight sounds in the cluster on the right in Figure 1, plotted on the three dimensions used for the cluster solution.

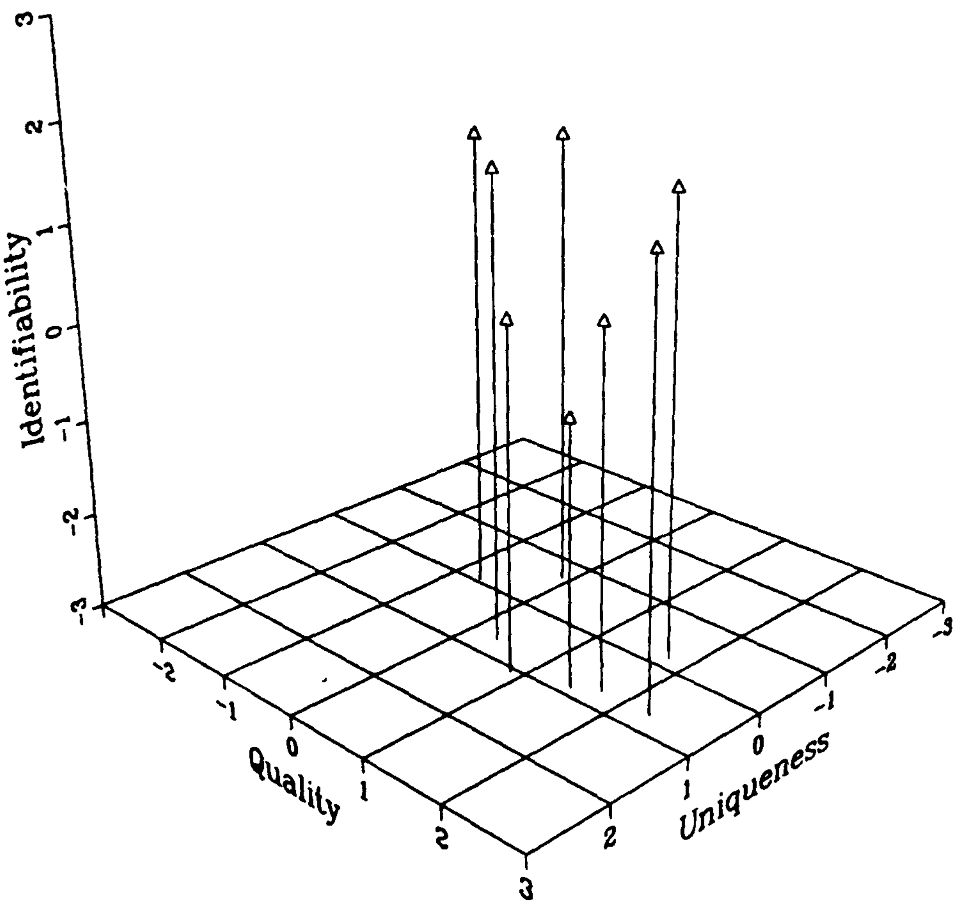


Figure 3. Cluster 2, consisting of the eight sounds in the second cluster from the right in Figure 1, plotted on the three dimensions used for the cluster solution.

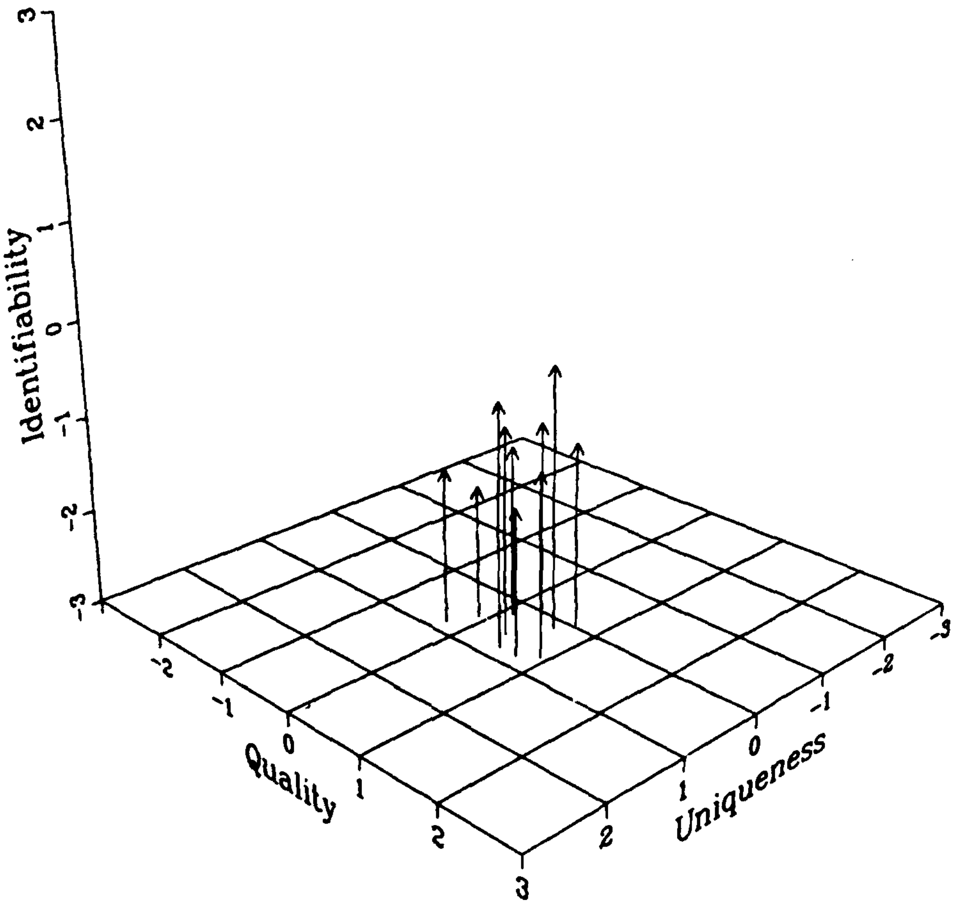


Figure 4. Cluster 3, consisting of the ten sounds in the third cluster from the right in Figure 1, plotted on the three dimensions used for the cluster solution.

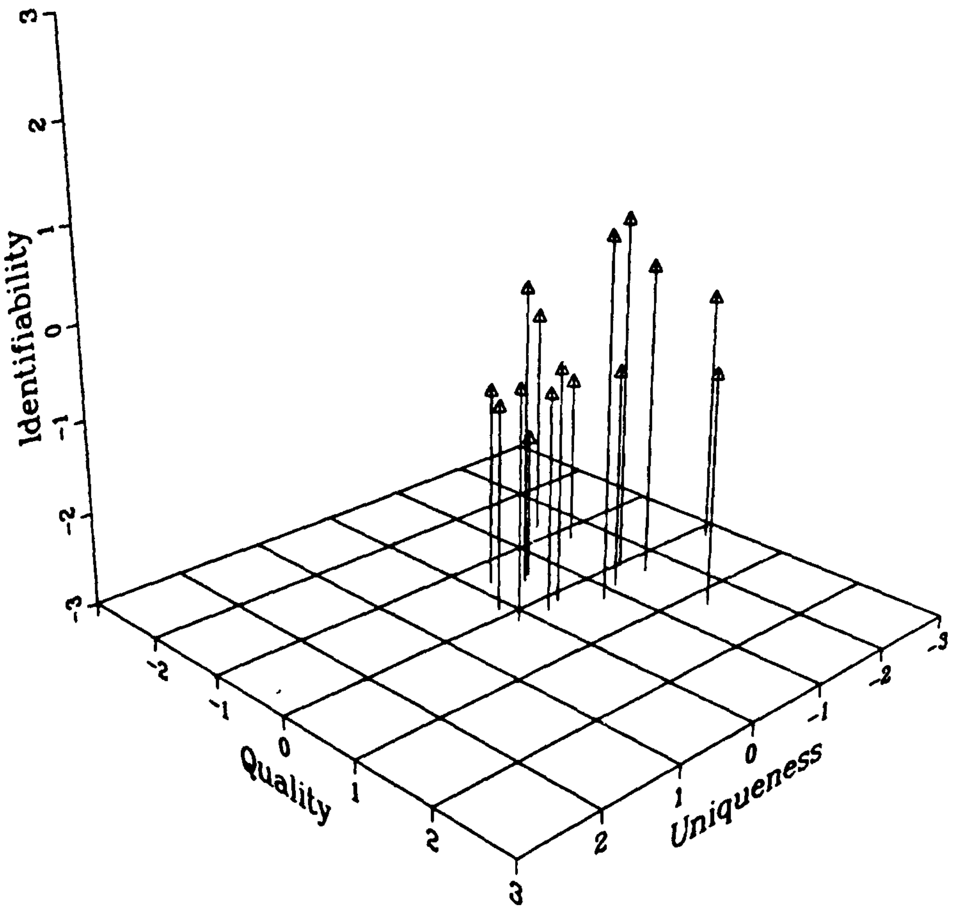


Figure 5. Cluster 4, consisting of the fifteen sounds in the first cluster on the left in Figure 1, plotted on the three dimensions used for the cluster solution.

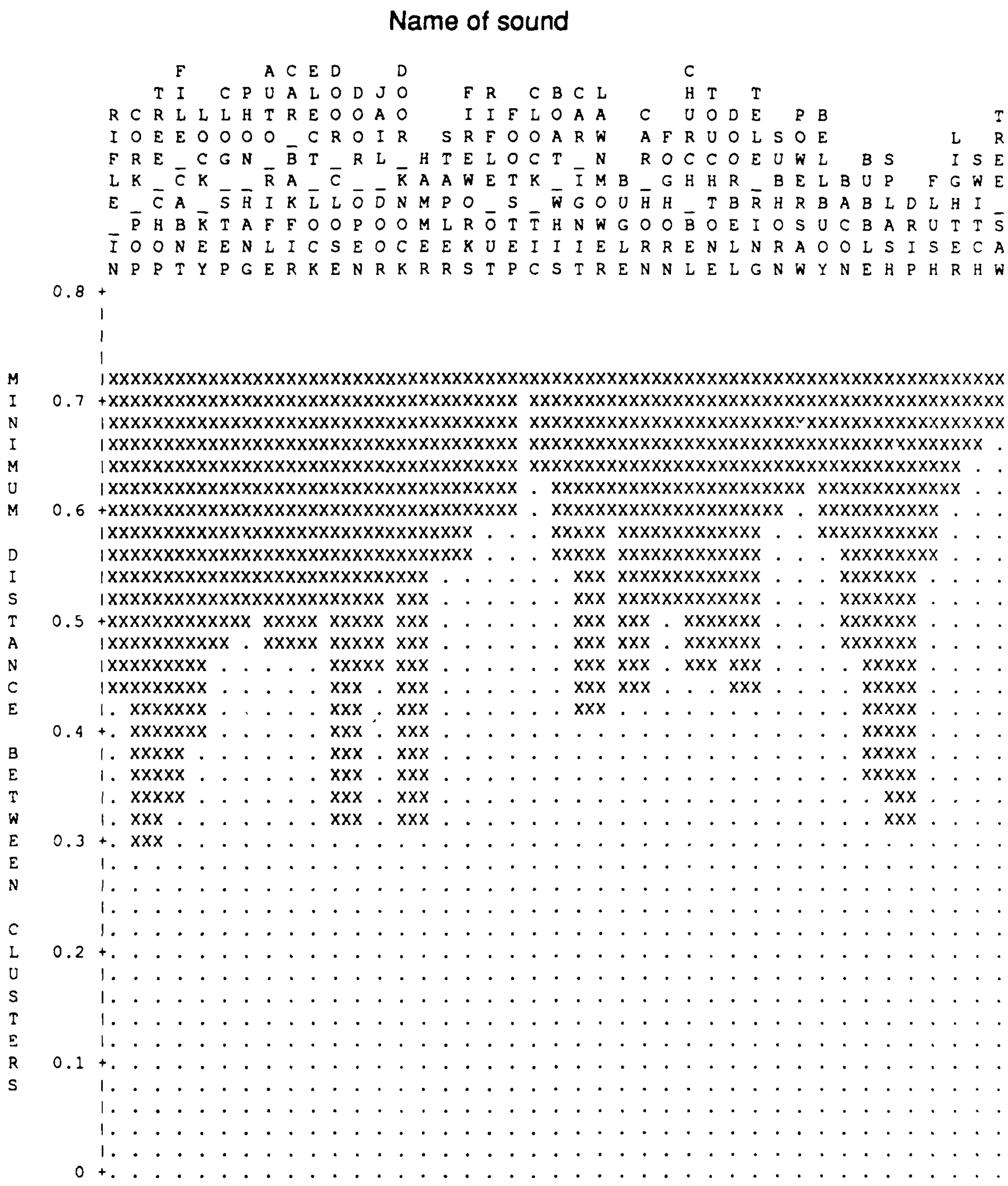


Figure 6. Single linkage cluster analysis of identification confusion index.

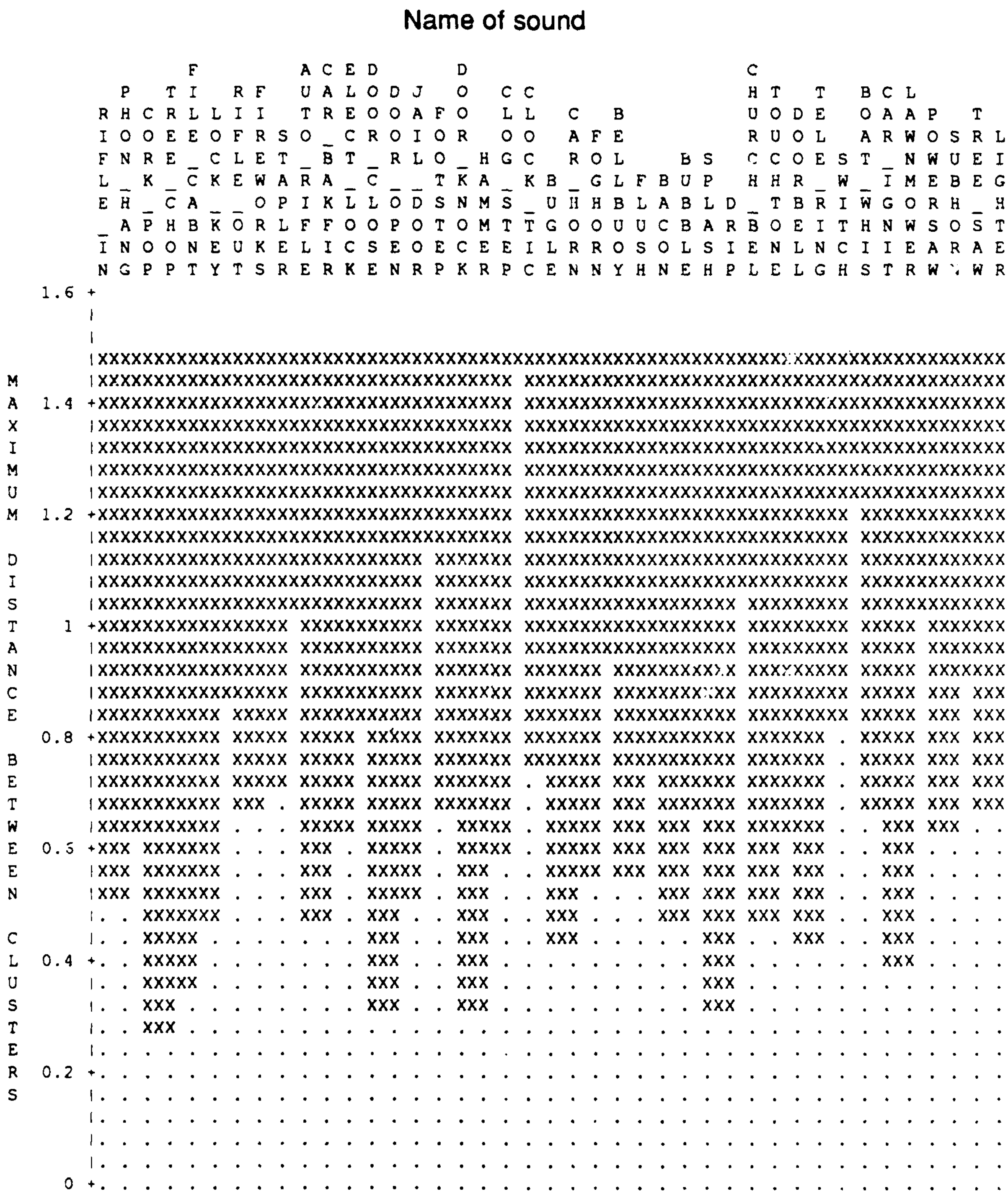


Figure 7. Complete linkage cluster analysis of identification confusion index.

Appendix A

Description and Source of 41 Sounds

Sound	Description	Source (Record,Vol, Side,Band)
1. Telephone ringing	high-pitched ringing	SFX,5,1,6
2. Clock	series of clicking sounds, ticking at moderate speed	SE,2,B,10
3. Car horn	blasting, honking sound of medium-pitched horn	SE,13,B,4
4. Doorbell	two separate chimes that run together, both chimes high-pitched, first chime has higher pitch than second	CBS,3,1,16
5. Automatic rifle	sporadic fire,4-5 shots	SE,13,B,13
6. Riverboat whistle	strong, high-pitched blast	SE,13,A,15
7. Water dripping	high-pitched water drip	Recorded
8. Bellbuoy	two quick, high-pitched chimes, lapping water and seagulls in background	AU,4,B,18
9. Foghorn	one blast of decreasing pitch	SE,13,A,13
10. Water bubbling	continuous, gurgling sound	AU,4,A,11
11. Bugle	notes increasing in pitch	AU,4,B,6
12. Rifleshot indoors	single shot,no echo	SE,2,A,21

13. Lawn mower	loud, continuous, pulsating sound of a motor	SFX,1,1,16
14. Church-bell tolling	echoing, high-pitched bell	SE,2,A,8
15. Swish	oar being rowed in water, sound of water flowing smoothly	SFX,2
16. Knocking on door	hard knocking on door	CBS,2,2,11
17. Flush	toilet flushing,rushing water	CBS,1,2,17
18. Footsteps	woman walking quickly in high heels	SE,13,B,4
19. Fireworks	powerful firecracker exploding, explosive, thundering quality	SFX,8,2,11
20. Cigarette lighter	lighter being lighted, quick, grinding, high-pitched metallic sound, quick hissing	Recorded
21. Touch tone telephone	beeping sounds produced by touch tone telephone, beeps are at different pitches	SFX,5,1,10
22. Door opening	door being opened,metallic lock opening, creaking of hinges in background	CBS,2,2,10
23. Bacon sizzling	sounds of bubbling,frying oil in a frying pan	AU,4,A,8
24. Hammering	series of pounding sounds, hammer pounding a nail	SFX,3,2,13
25, Submarine dive horn	quick blast of increasing and then decreasing pitch	SFX,1,2,21
26. Person walking in clogs	series of footsteps of person walking at a leisurely pace in wooden clogs. Each step contains two impact sounds of clogs hitting a floor.	SFX,3,1,25
27. Ignition of car	increasing pitch of car ignition	SE,13,A,9

28. Chopping of tree	loud impact sound of sharp object cutting and pounding into a tree	SFX,1,1,18
29. Power saw	high pitched metallic grinding	SFX,7,2,23
30. Door latched	two latching sounds, slightly muffled	SFX,1,2,5
31. Cork popping	loud popping sound	SFX,5,1,13
32. File cabinet	sound of metallic wheels rolling on a metallic track followed by the closing of the drawer	SFX,3,2,6
33. Door closing	door being slammed into door frame, metallic lock closing	CBS,2,2,9
34. Car backfire	one backfire, explosive quality, trace of sputtering before onset of backfire	SE,13,A,9
35. Jail door closing	loud impact sound of a heavy metallic door sliding shut with loud click of lock locking	SFX,1,2,3
36. Rifle shot outdoors	single shot,echo	SE,2,A,19
37. Light switch	pull light switch with two clicks, metallic sound at end	Recorded
38. Stapler	stapler being pressed	Recorded
39. Telephone being hung up	plastic phone receiver being dropped into its cradle	SFX,5,1,8
40. Sawing of tree	moderate sawing speed,hand saw	SFX,1,1,21
41. Electric lock	sequence of buzz and then clicking sound of lock opening	SFX,1,1,24

References for sources of recordings

SE,2: Valentino, T.J.(Producer). Sound Effects Vol.II [Album].New York, N.Y.: Thomas J Valentino Inc.

SE,13: Valentino, T.J.(Producer). Sound Effects Vol.XIII[Album]. New York, N.Y.: Thomas J Valentino Inc.

AU,4: Holzman, J.(Producer). Authentic Sound Effects Vol.IV[Album]. New York, N.Y.: The Elektra Corporation.

CBS,1.2.3: Hoppe, E. and Dulberg,J.(Producers). The New CBS Audio-File Sound Effects Library, Vol.II [Album] (1982).New York, N.Y.: CBS Records. (CBS,1 represents the first record within the volume, CBS,2 represents the second record, and CBS,3 represents the third record).

SFX,1,2,3,5,7,8: White, V.(Producer). SFX Sound Effects [Albums] New York, N.Y.: Folkways Records and Service Corp.

Appendix B

Scales Used to Solicit Perceptual and Cognitive Ratings

1. Rate the identifiability of this sound.

___1___ ___2___ ___3___ ___4___ ___5___
not very identifiable — very identifiable

2. How easily does a mental picture of this sound come to mind?

___1___ ___2___ ___3___ ___4___ ___5___
not very easily — very easily

3. How easily does the mental picture of the person or object which caused this sound come to mind?

4. How easily does the mental picture of the action of this sound come to mind?

___1___ ___2___ ___3___ ___4___ ___5___
not very easily — very easily

5. How necessary is it to envision this sound in a sequence of sounds in order to identify it?

___1___ ___2___ ___3___ ___4___ ___5___
not very necessary — very necessary

6. To what extent is this sound a necessary part of the sequence in the previous question?

___1___ ___2___ ___3___ ___4___ ___5___
not very necessary — very necessary

7. How loud do you think this sound was?

___1___ ___2___ ___3___ ___4___ ___5___
very soft — very loud

8. How many sounds can you think of which are similar to this one?

___1___ ___2___ ___3___ ___4___ ___5___
not very many — very many

9. How many events can you think of which could have caused this sound?

___1___ ___2___ ___3___ ___4___ ___5___
not very many — very many

10. How easily are you able to think of words to describe this sound?

___1___ ___2___ ___3___ ___4___ ___5___
not very easily — very easily

11. How easily are you able to think of words which describe the person or object which caused the sound?

___1___ ___2___ ___3___ ___4___ ___5___
not very easily — very easily

12. How easily are you able to think of words which describe the action which caused the sound?

___1___ ___2___ ___3___ ___4___ ___5___
not very easily — very easily

13. How similar is this sound to your mental stereotype?

___1___ ___2___ ___3___ ___4___ ___5___
very similar — very different

14. How familiar does this sound seem to you?

___1___ ___2___ ___3___ ___4___ ___5___
not very familiar — very familiar

15. How clear was this sound in quality?

___1___ ___2___ ___3___ ___4___ ___5___
not very clear — very clear

16. How many sounds can you think of that you would place in the same category as this one?

___1___	___2___	___3___	___4___	___5___
not very many				very many

17. Rate the following dimensions according to your feelings about this sound?

___1___	___2___	___3___	___4___	___5___
soft				hard

___1___	___2___	___3___	___4___	___5___
round				angular

___1___	___2___	___3___	___4___	___5___
dull				sharp

___1___	___2___	___3___	___4___	___5___
relaxed				tense

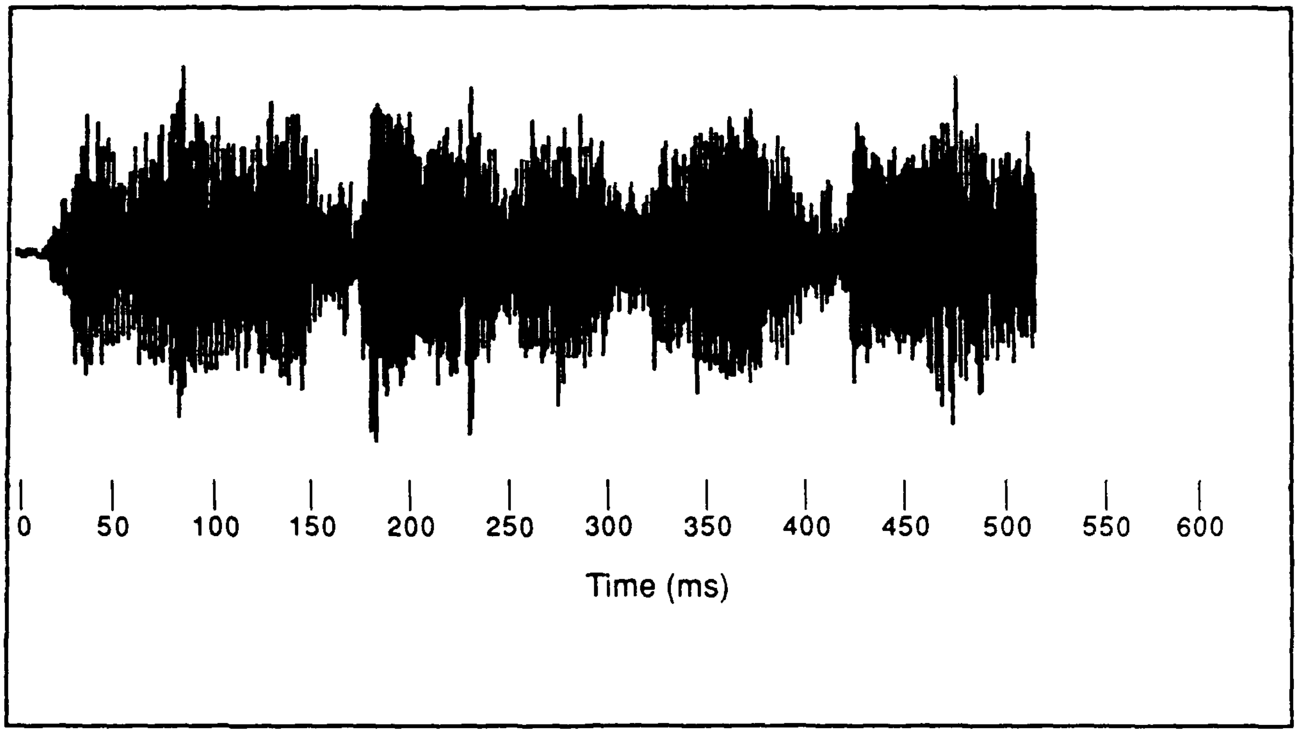
___1___	___2___	___3___	___4___	___5___
very pleasant				very unpleasant

___1___	___2___	___3___	___4___	___5___
interesting				boring

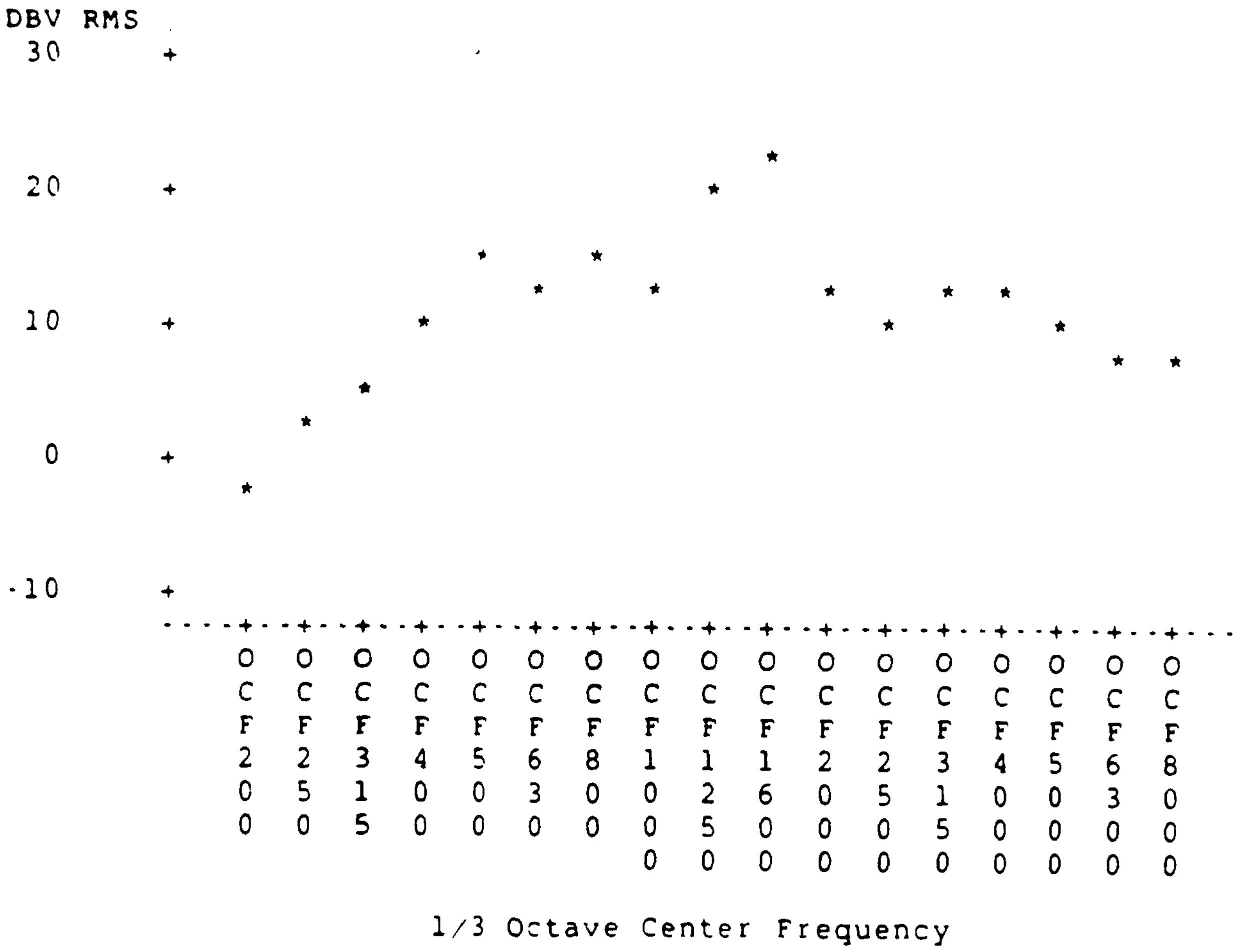
___1___	___2___	___3___	___4___	___5___
compact				scattered

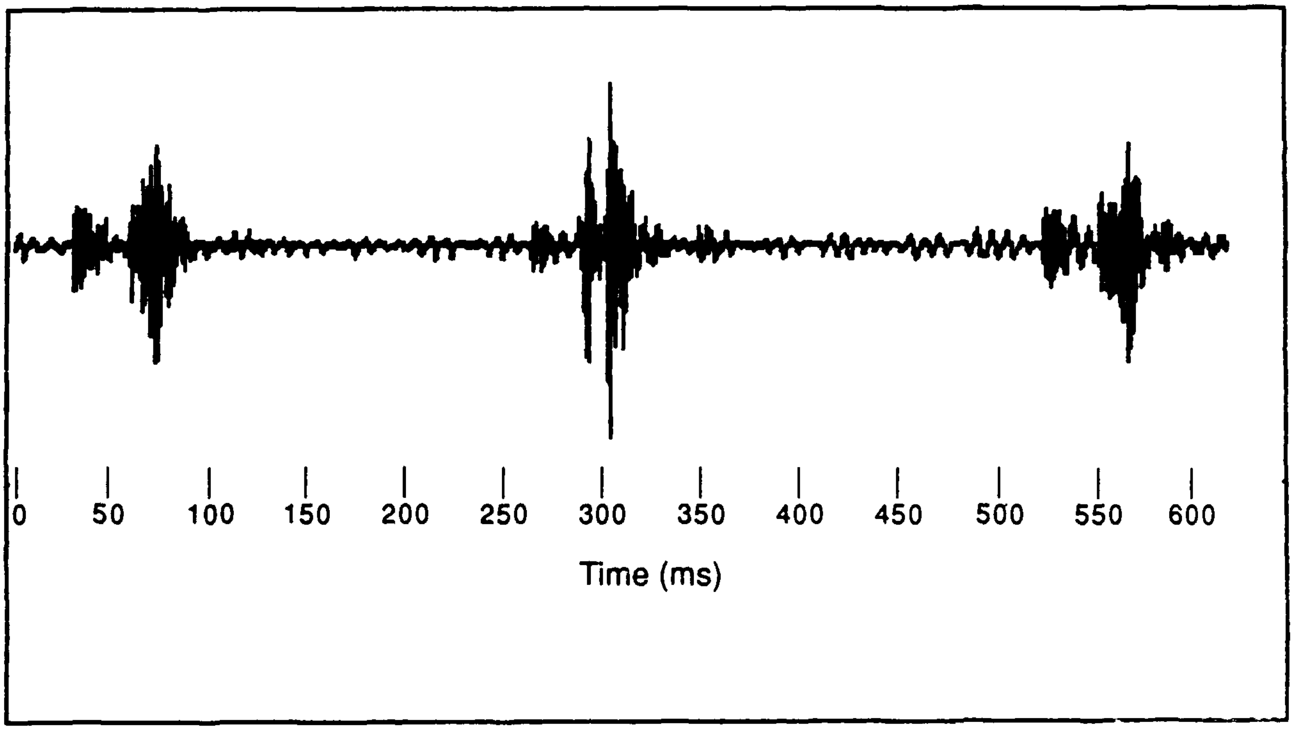
18. Sounds generally have meanings associated with them. Based upon what you think the sound means - rate the nature of the meaning on the following scale. At one end are sounds which literally refer to only the events which caused the sound waves. At the other end are sounds which arbitrarily symbolize something unrelated to the sound waves. In the middle are metaphorical sounds whose meanings depend in part on the physical character of the sound but which also have a meaning beyond their physical acoustics. What is the nature of the meaning of the sound?

1. symbolic
2. metaphorical
3. literal

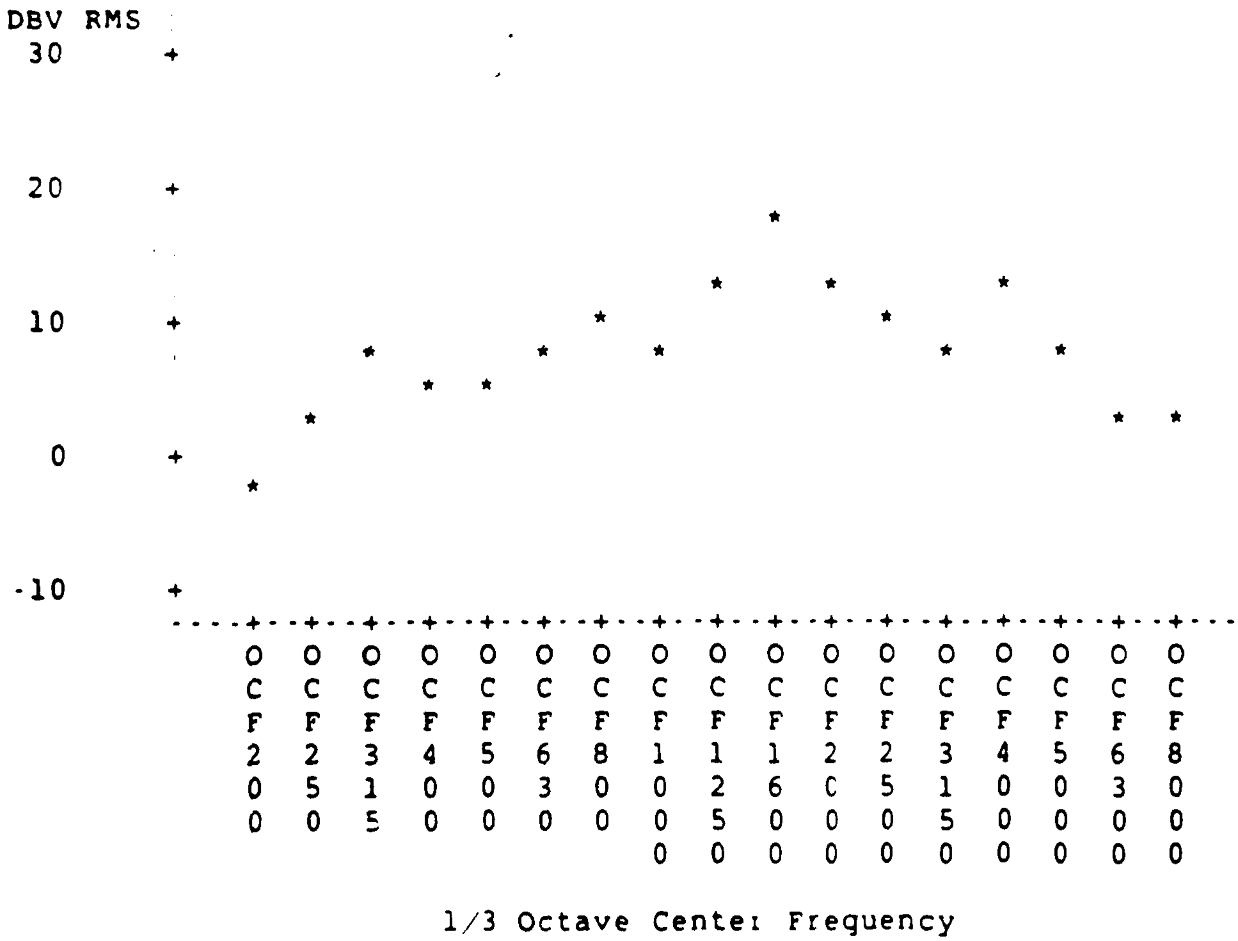


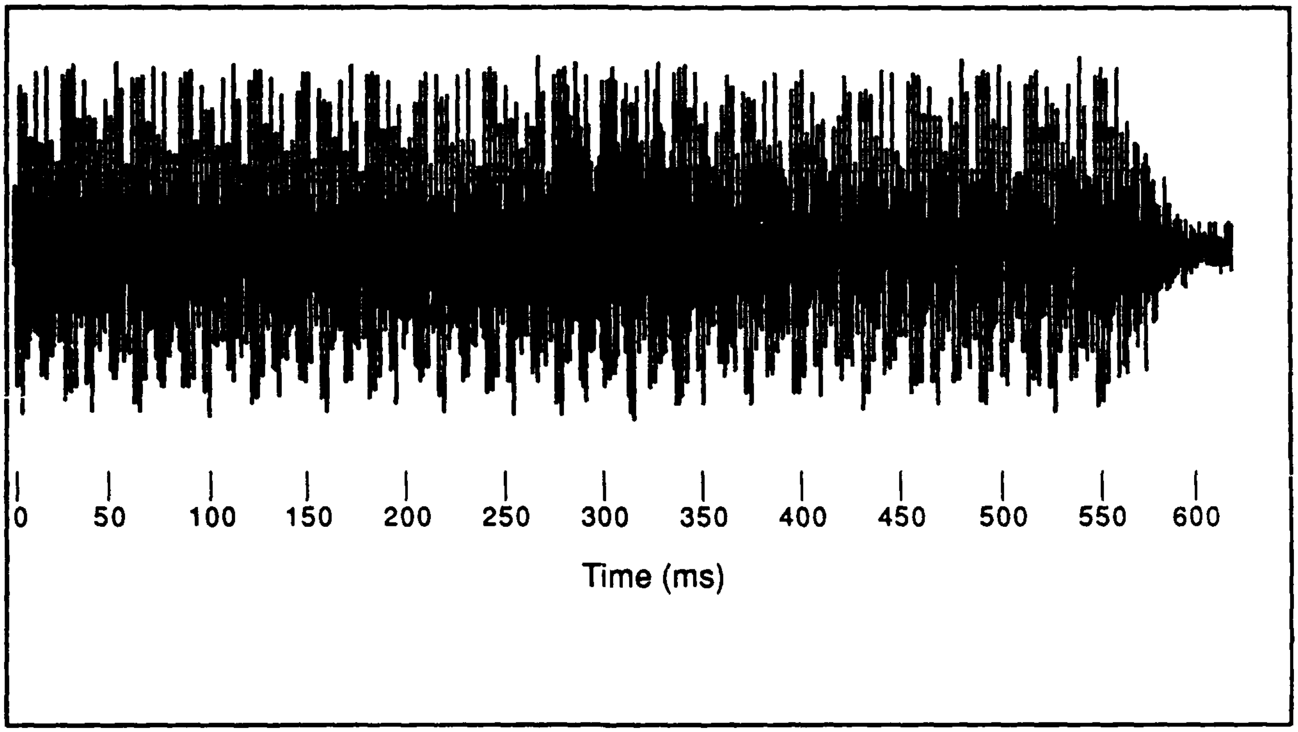
Telephone ring





Clock ticking

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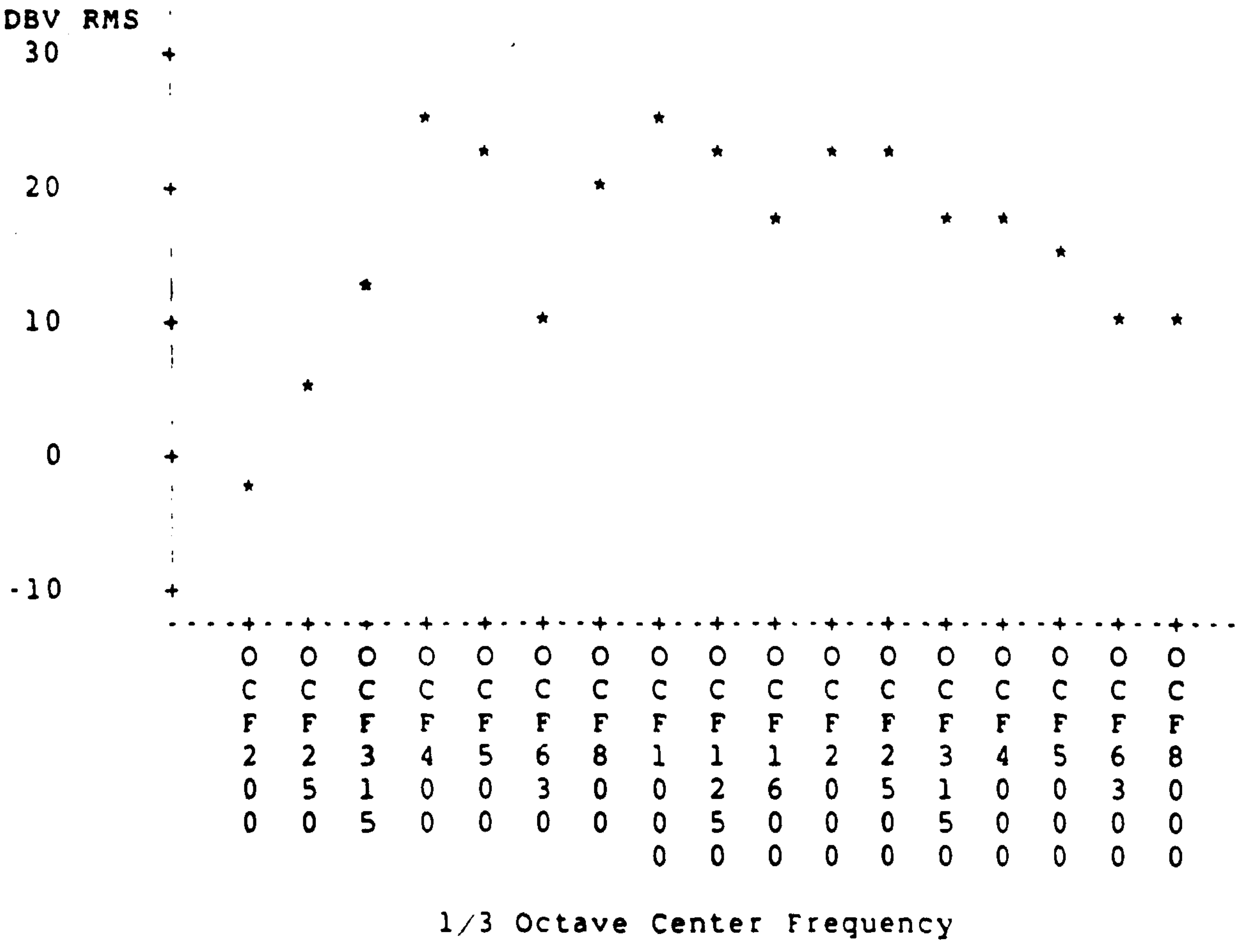
Car Horn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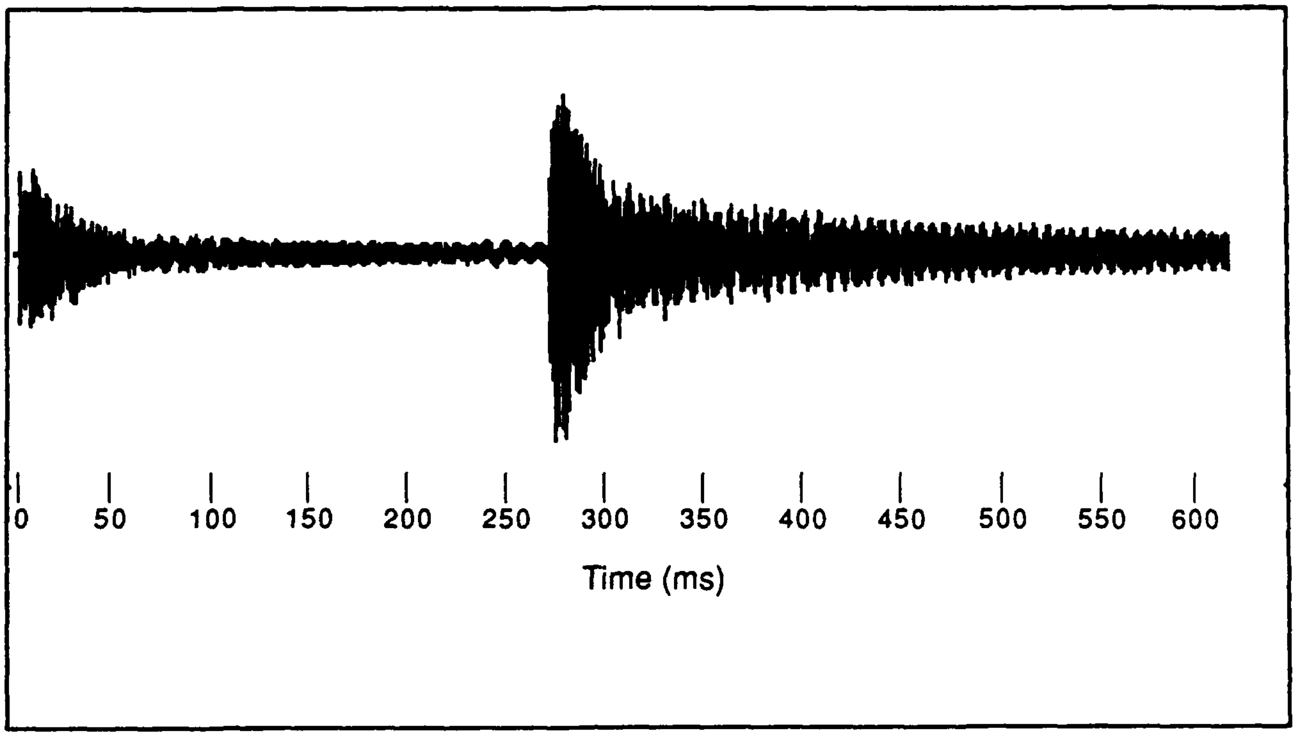
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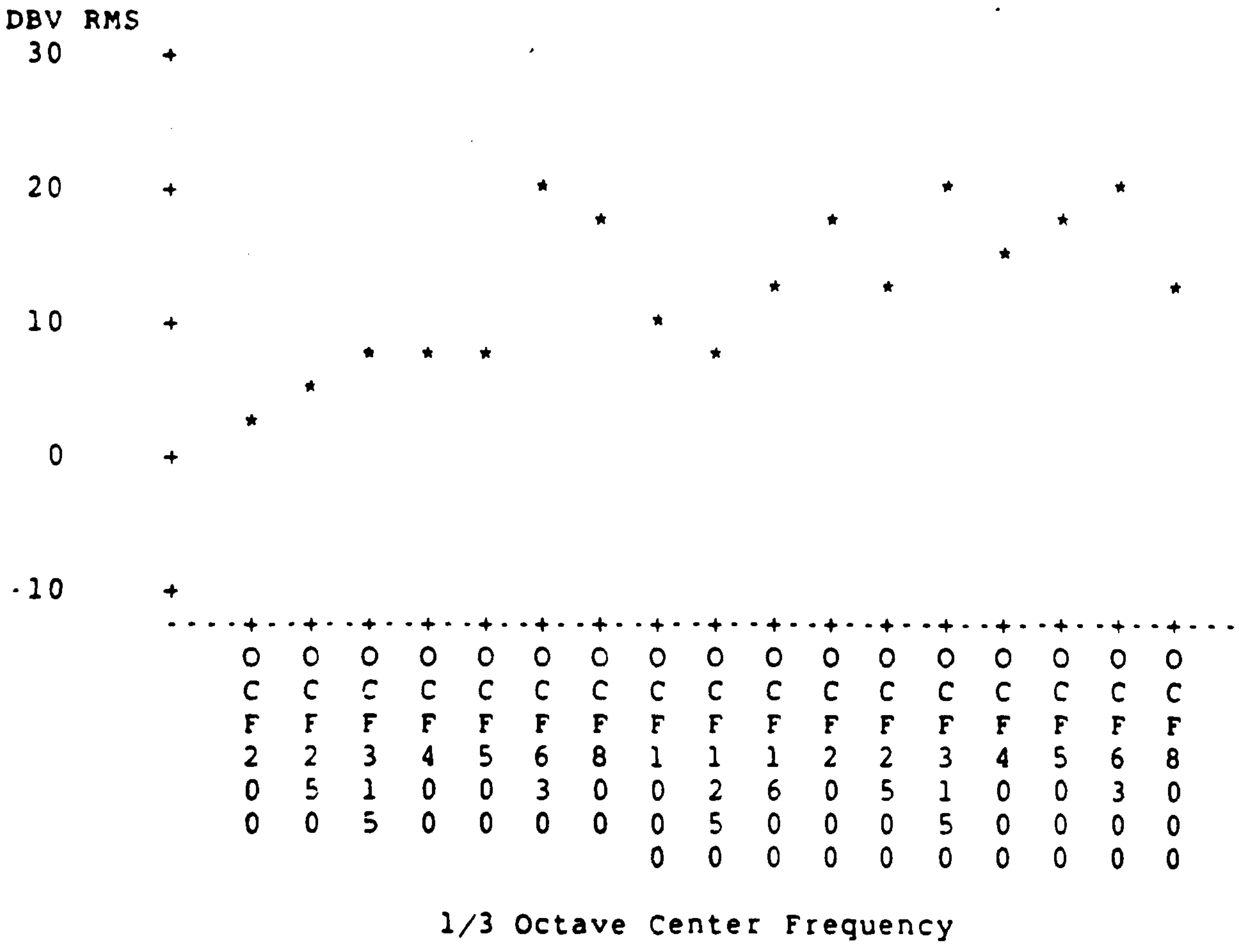
Doorbell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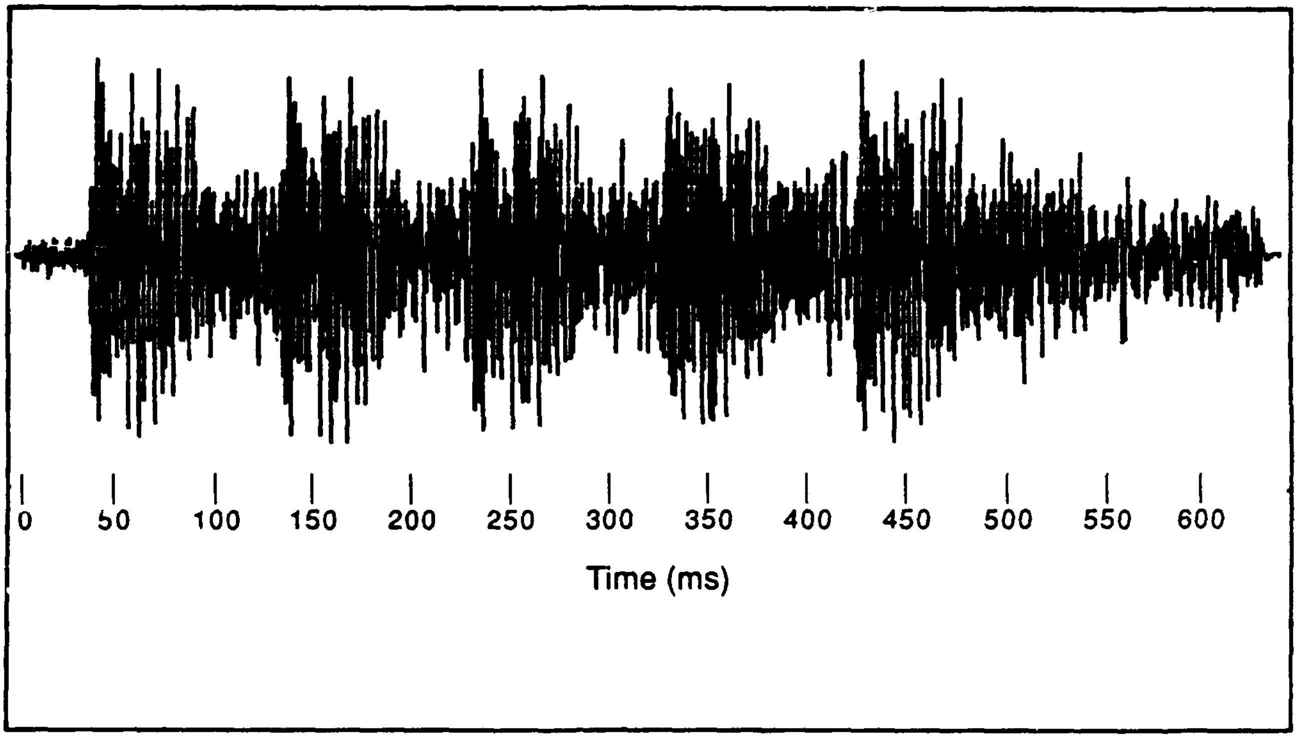
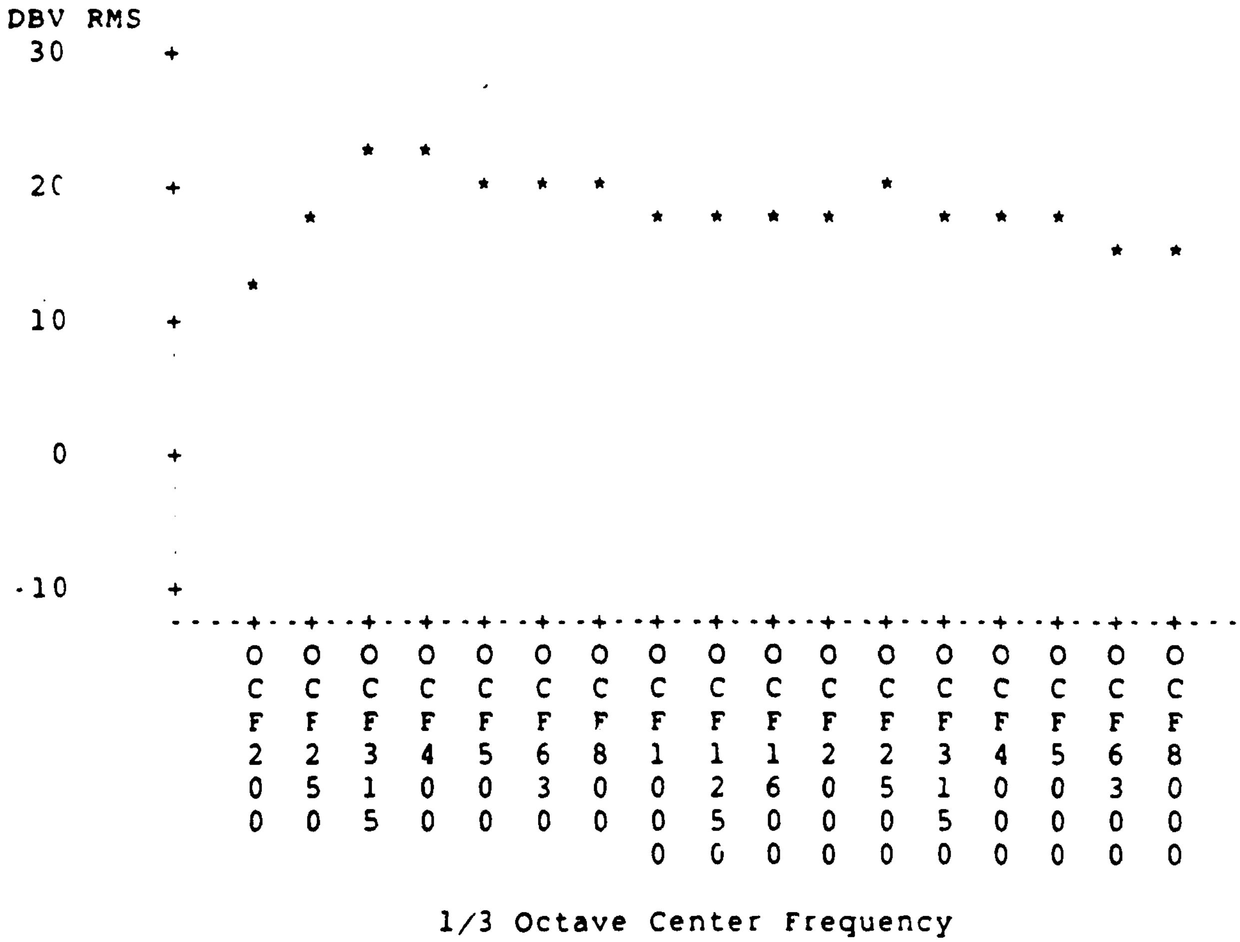
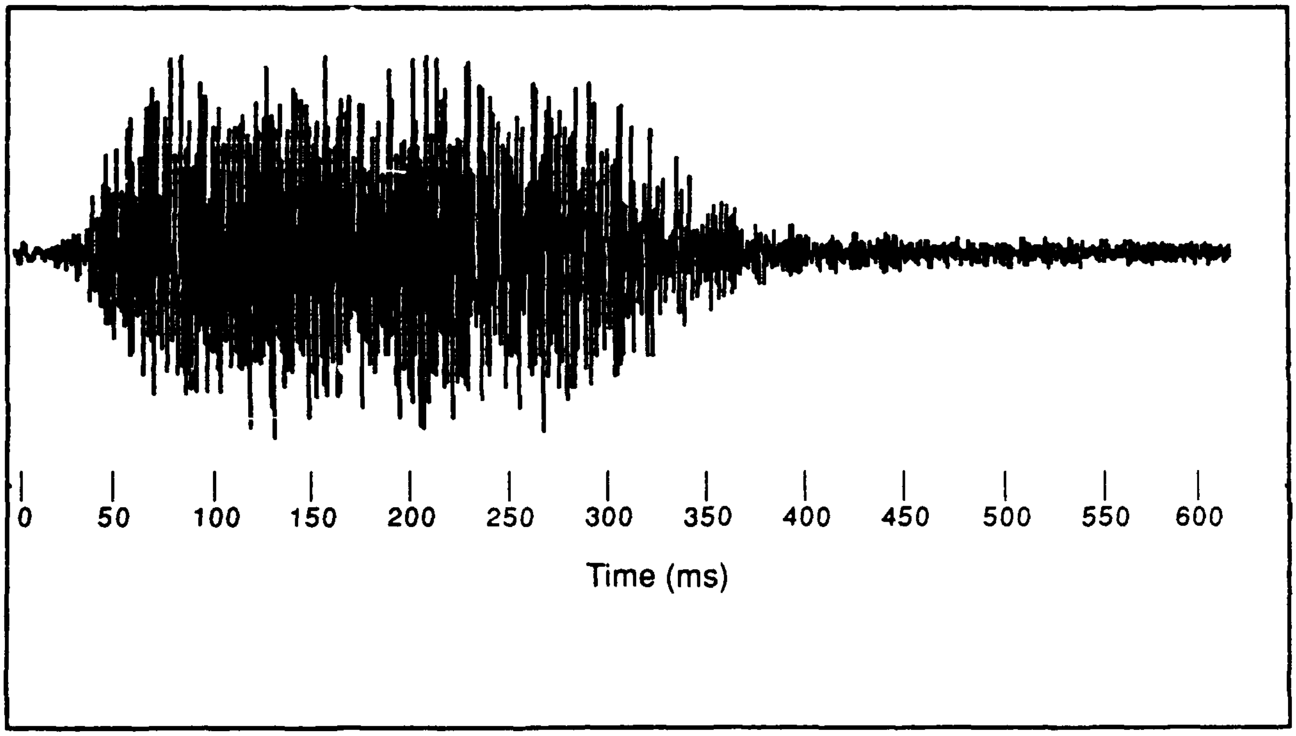
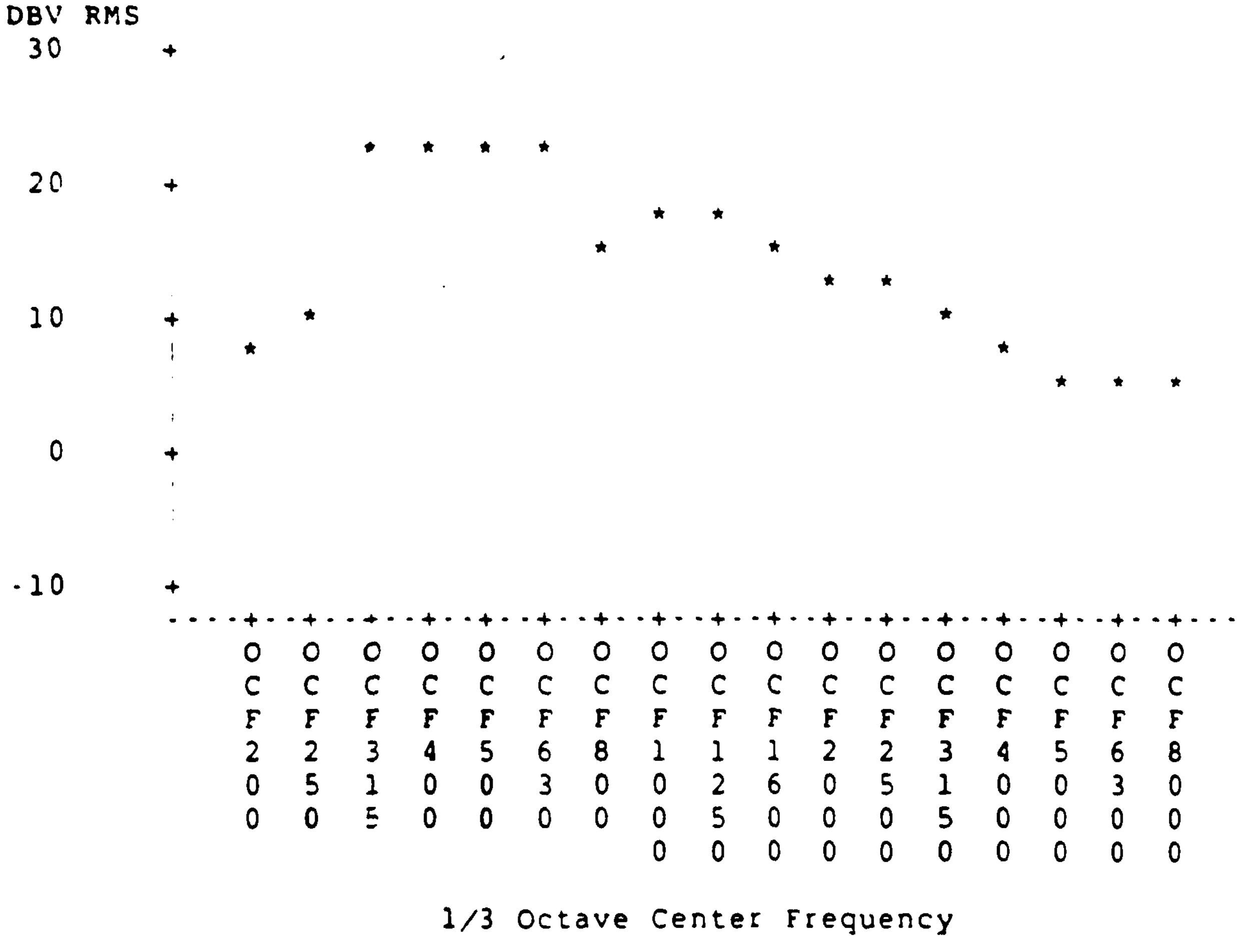


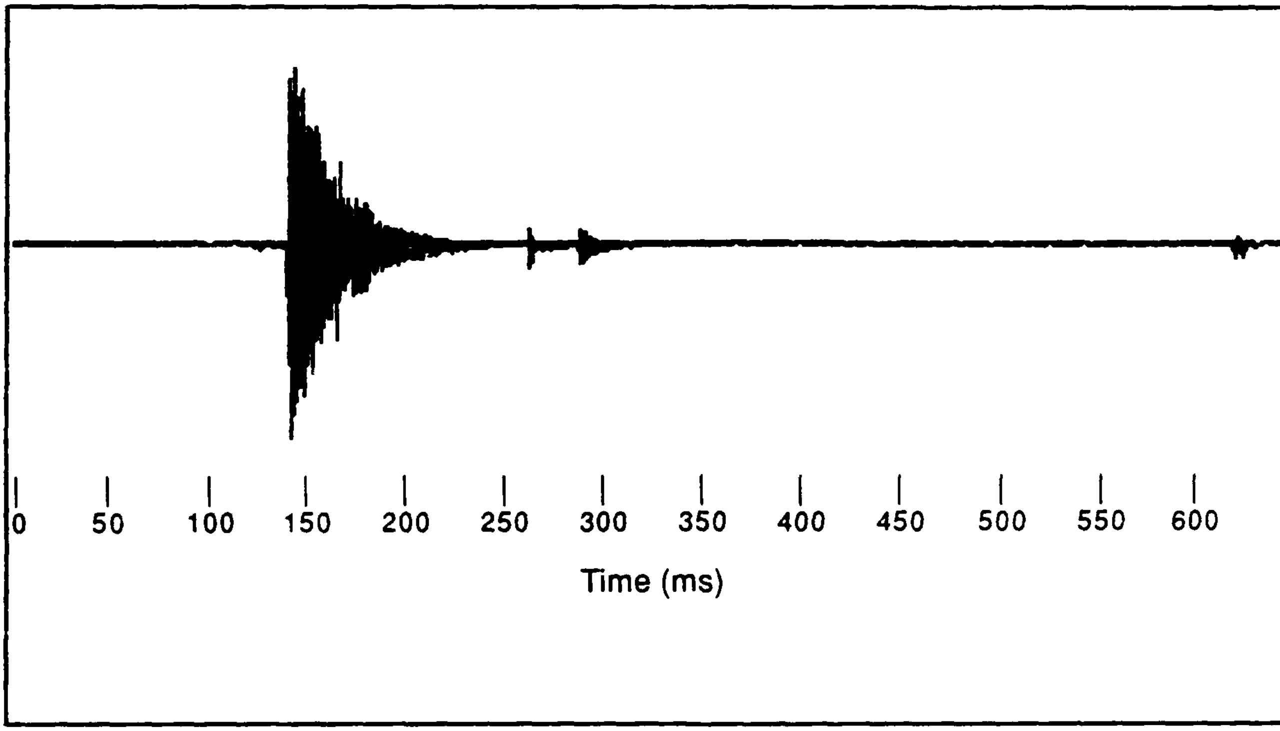
Automatic rifle





Riverboat whistle

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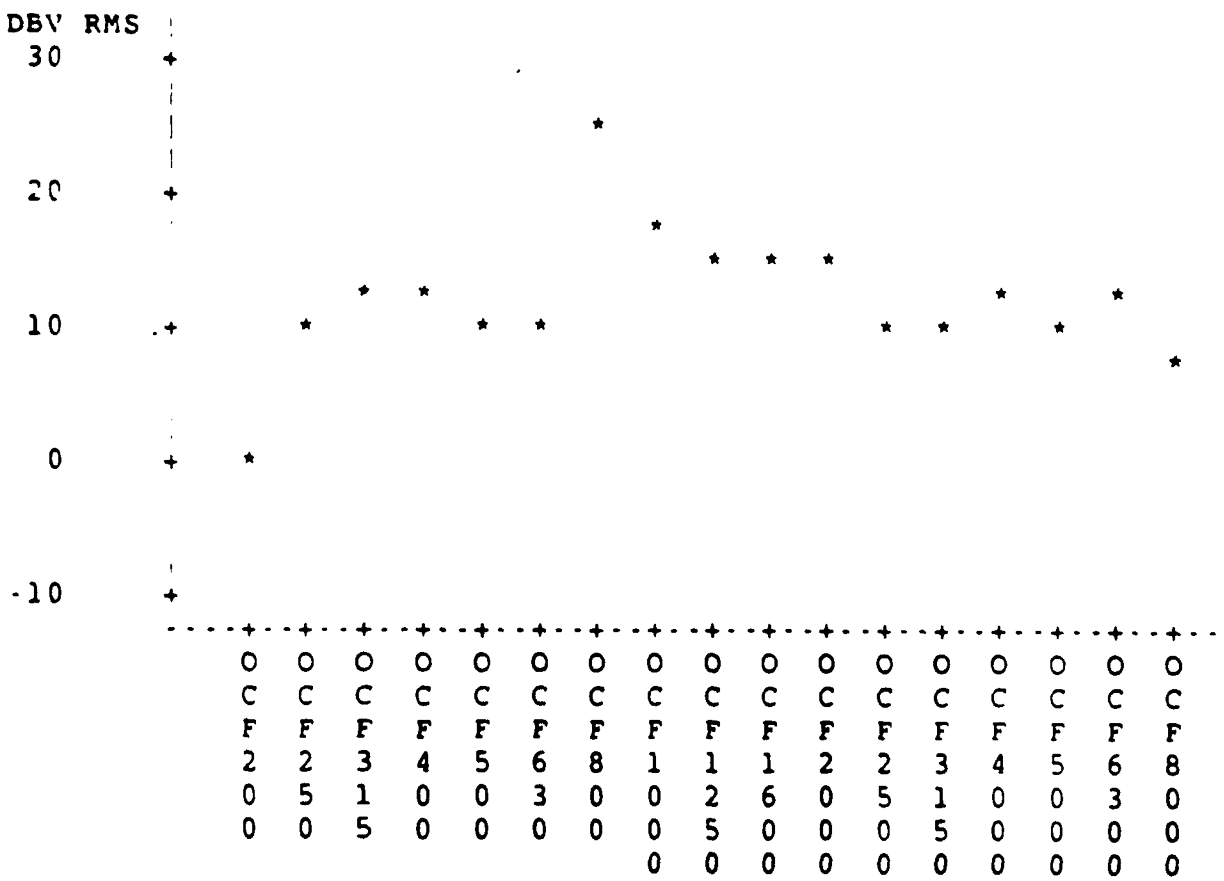
Water drip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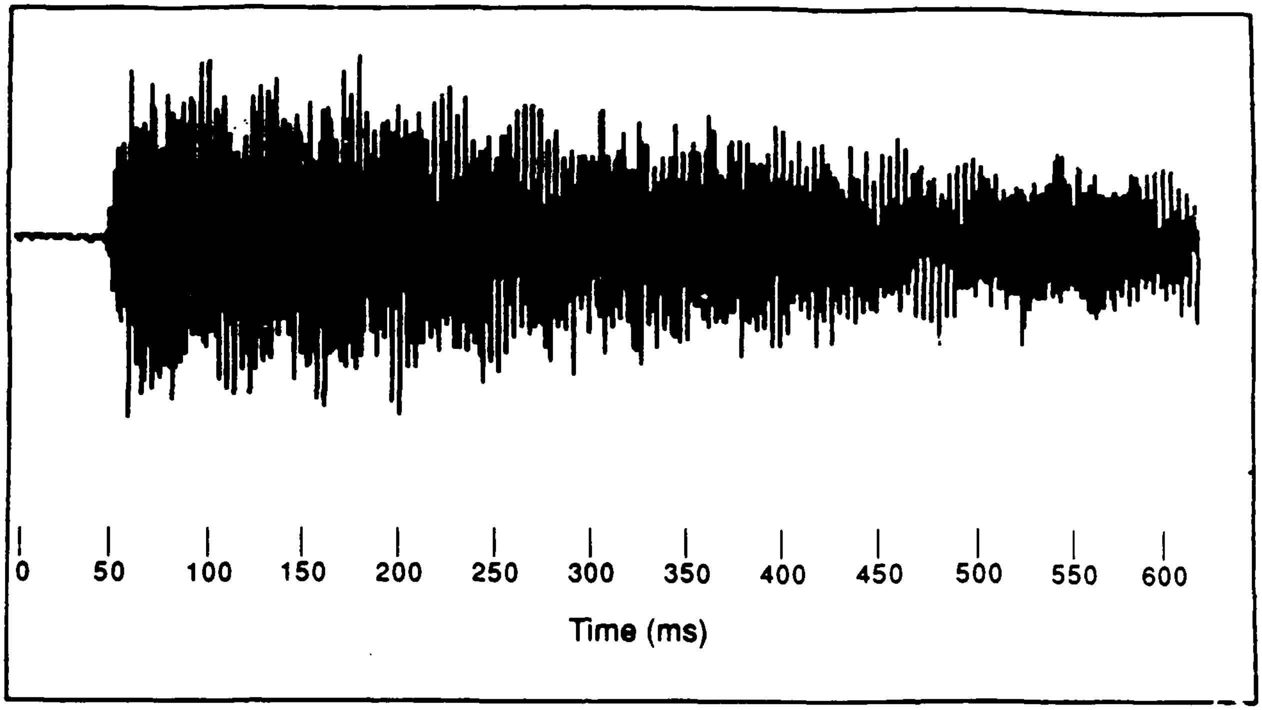
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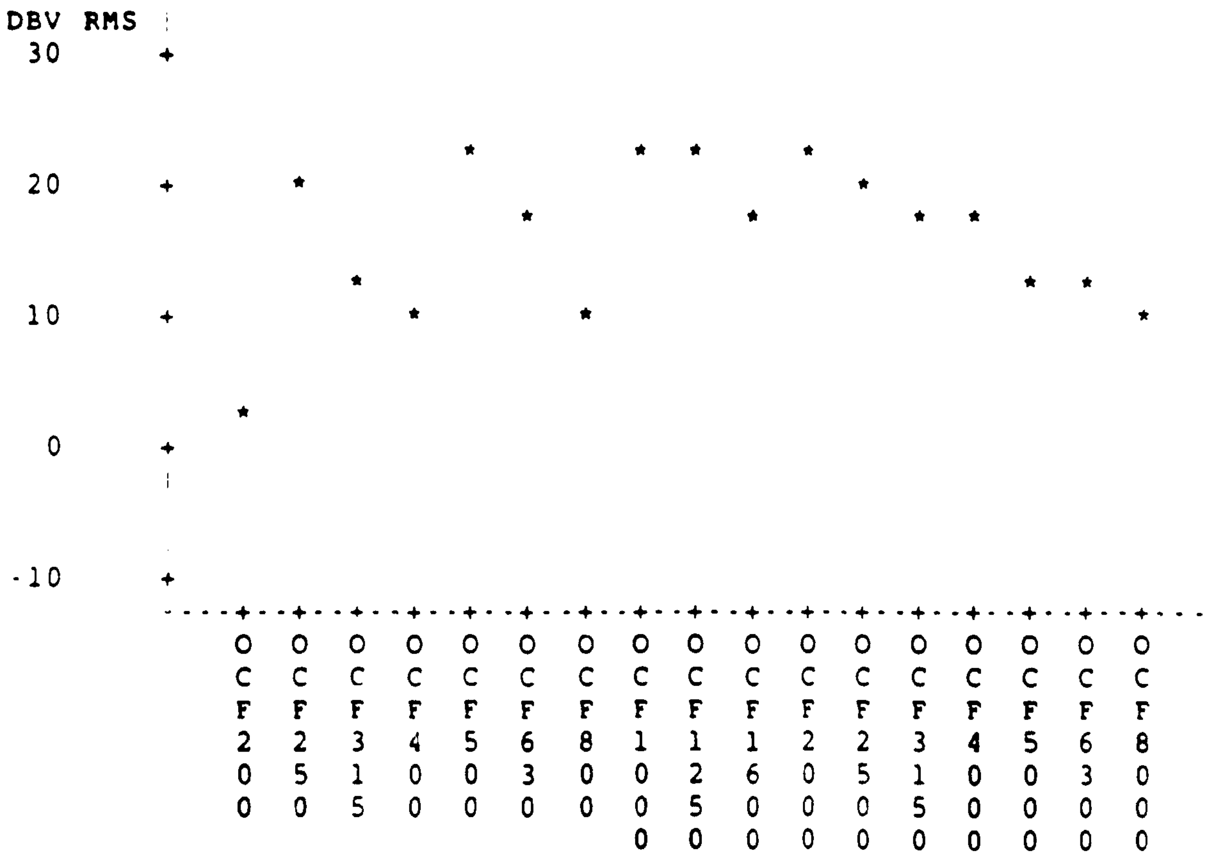
Bell buoy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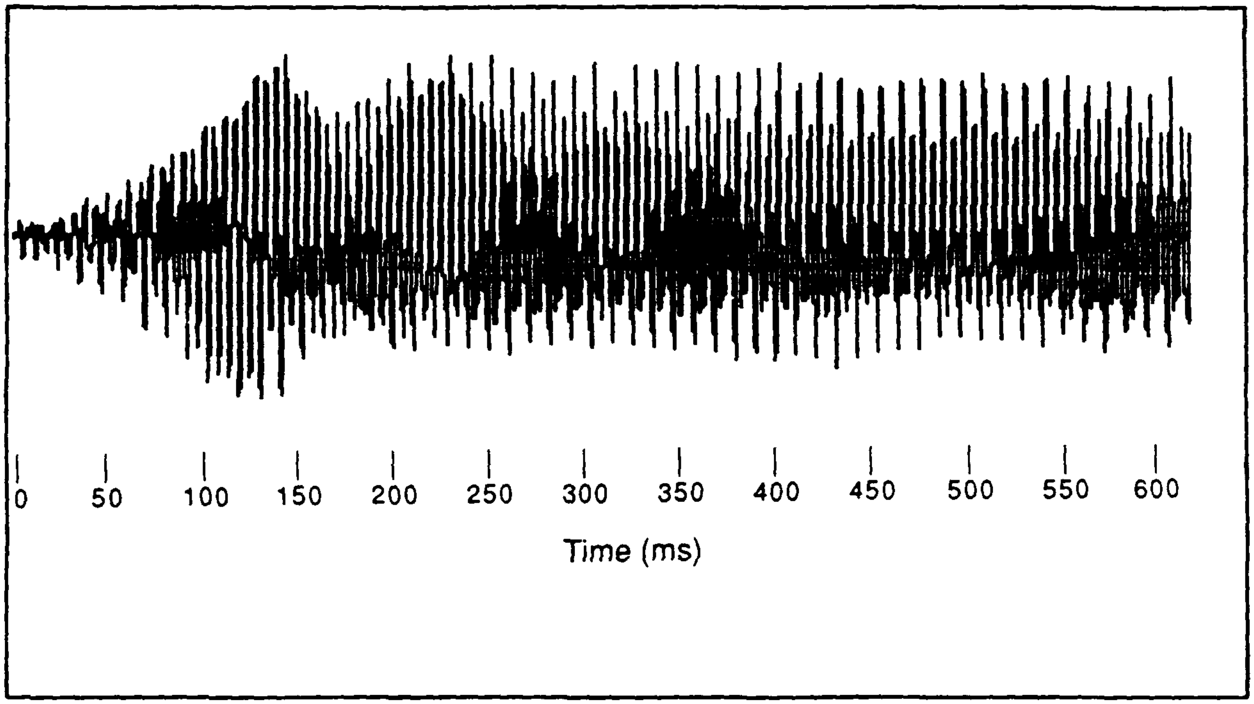
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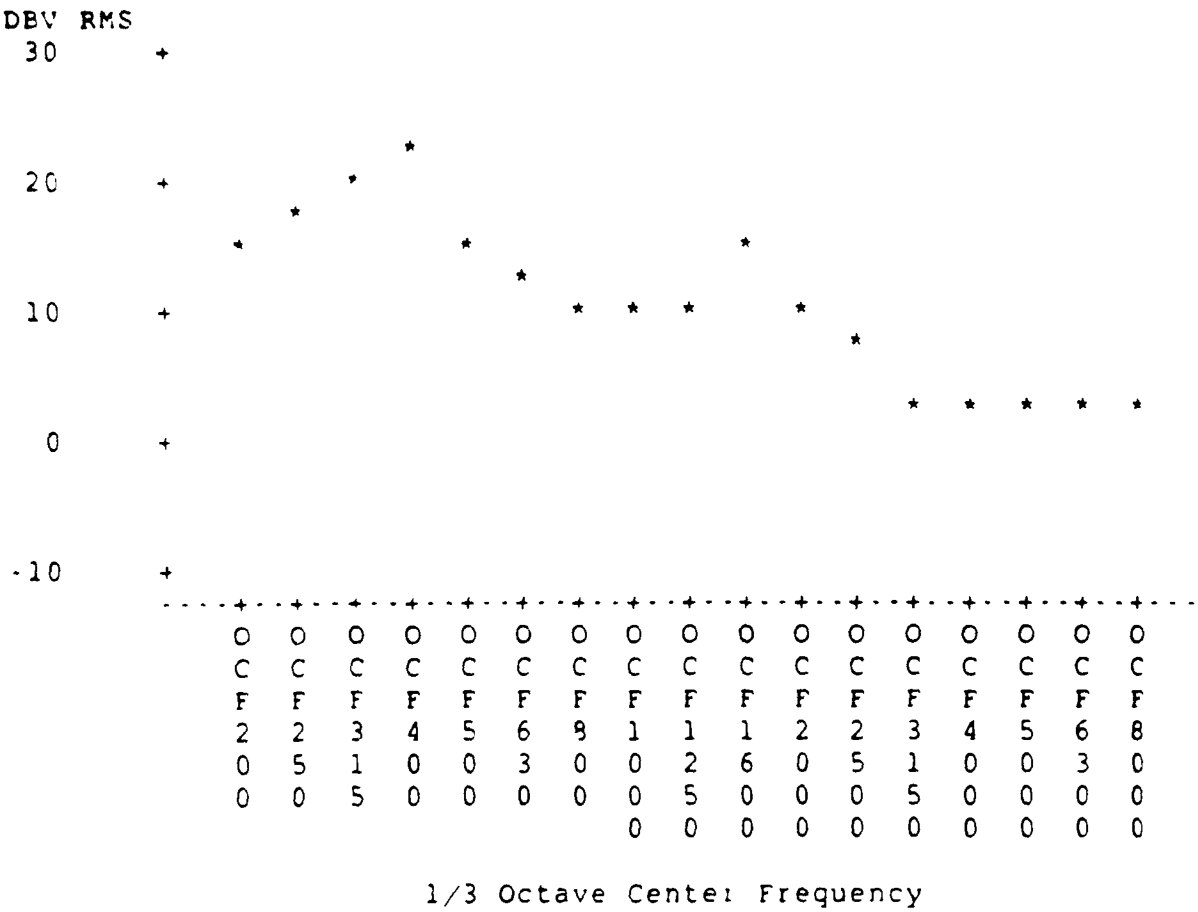
Foghorn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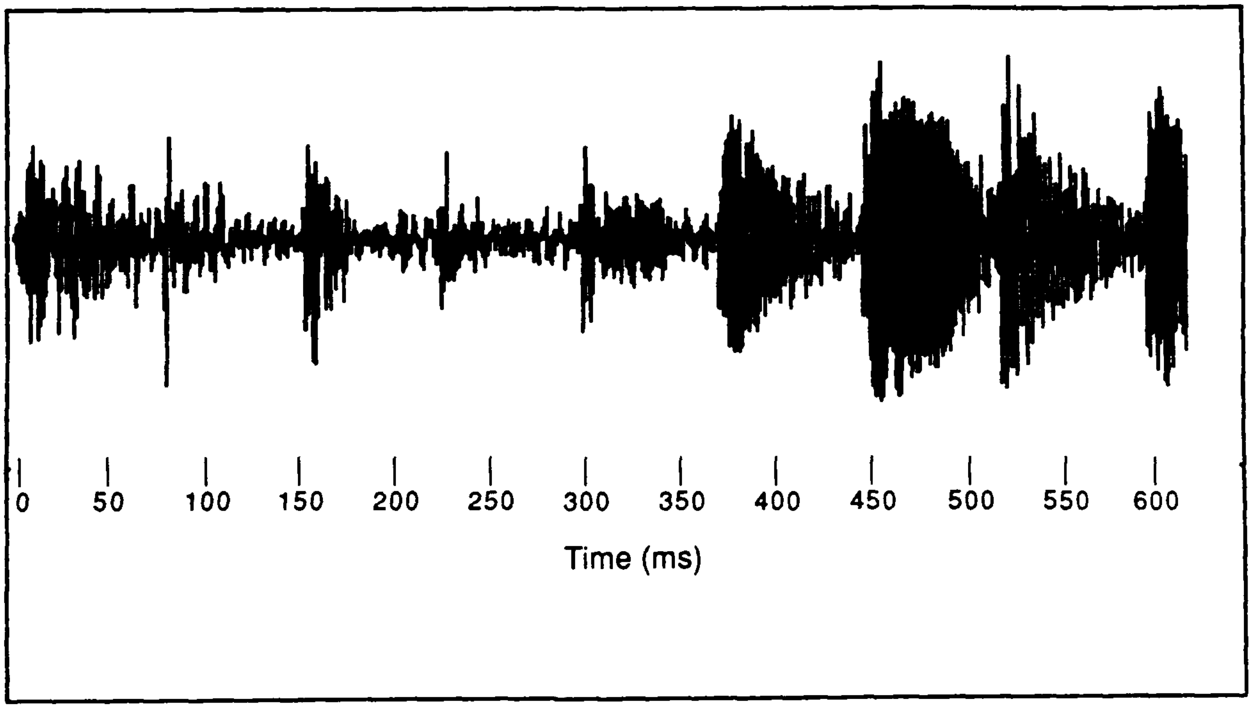

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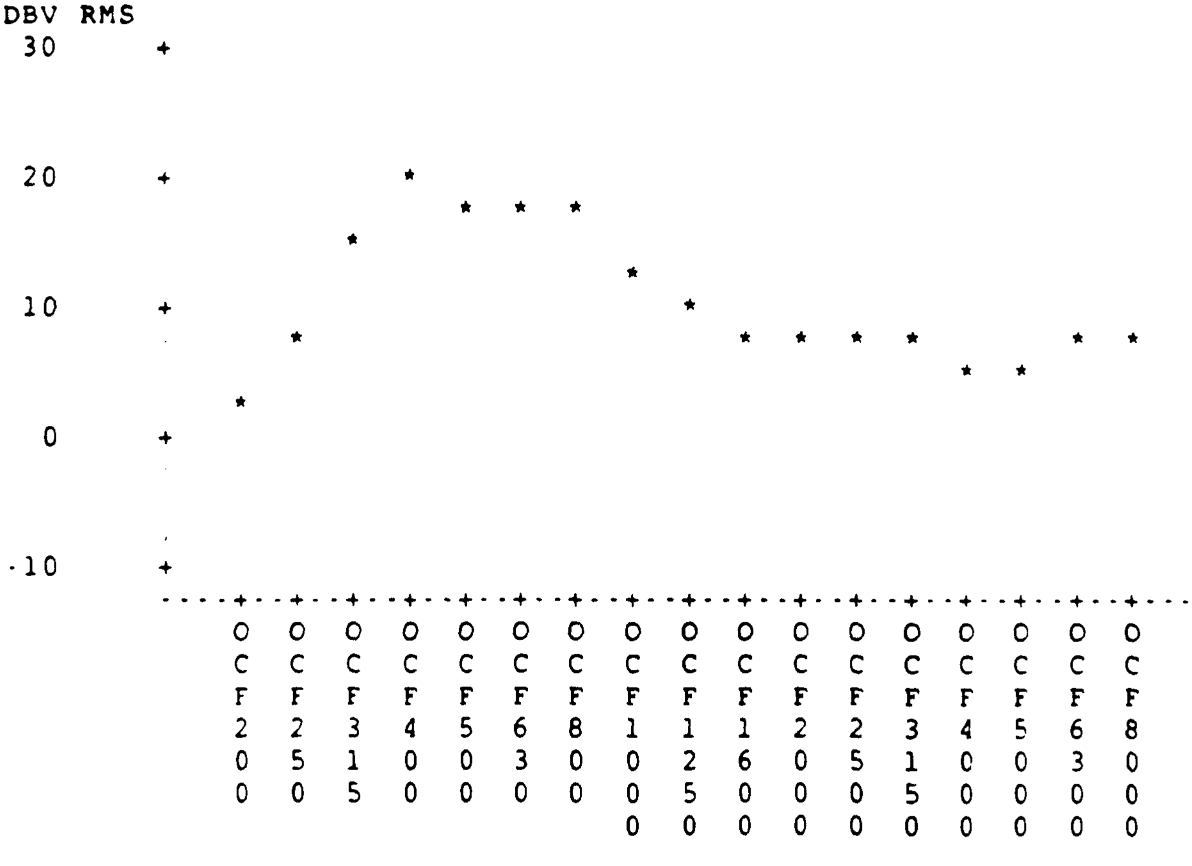

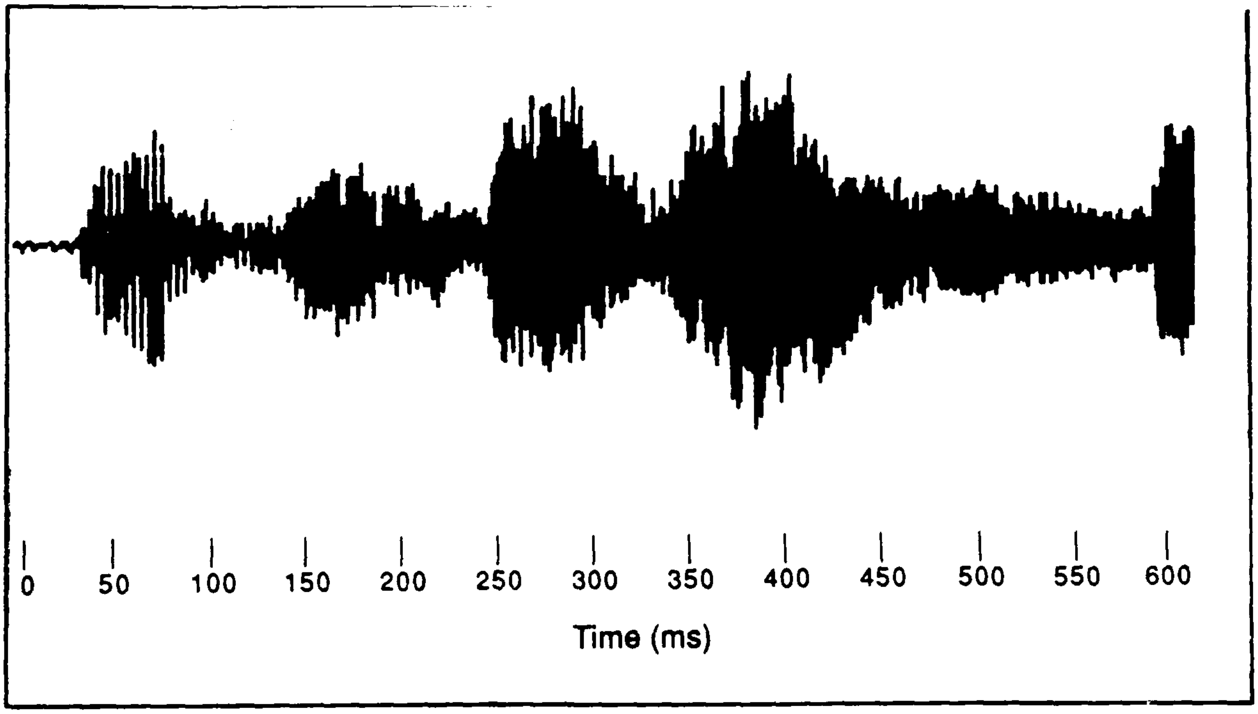

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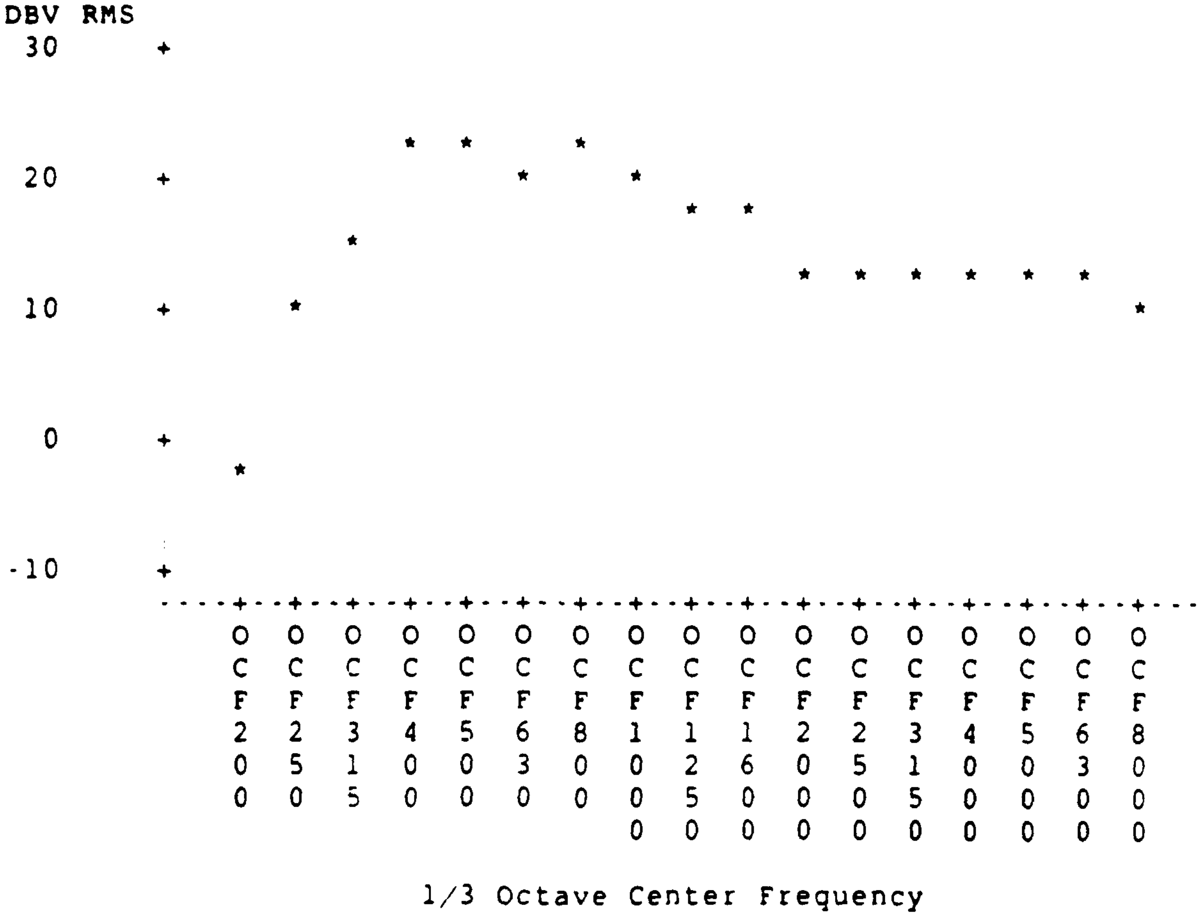
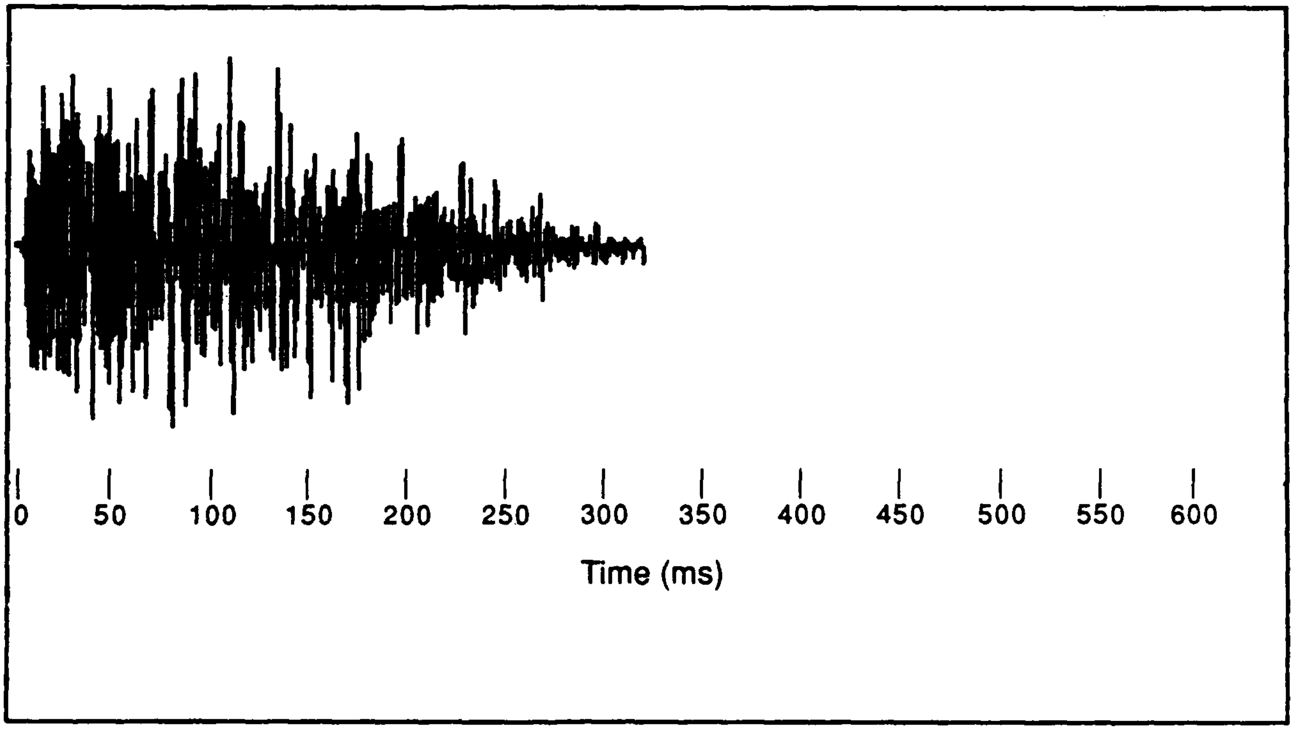
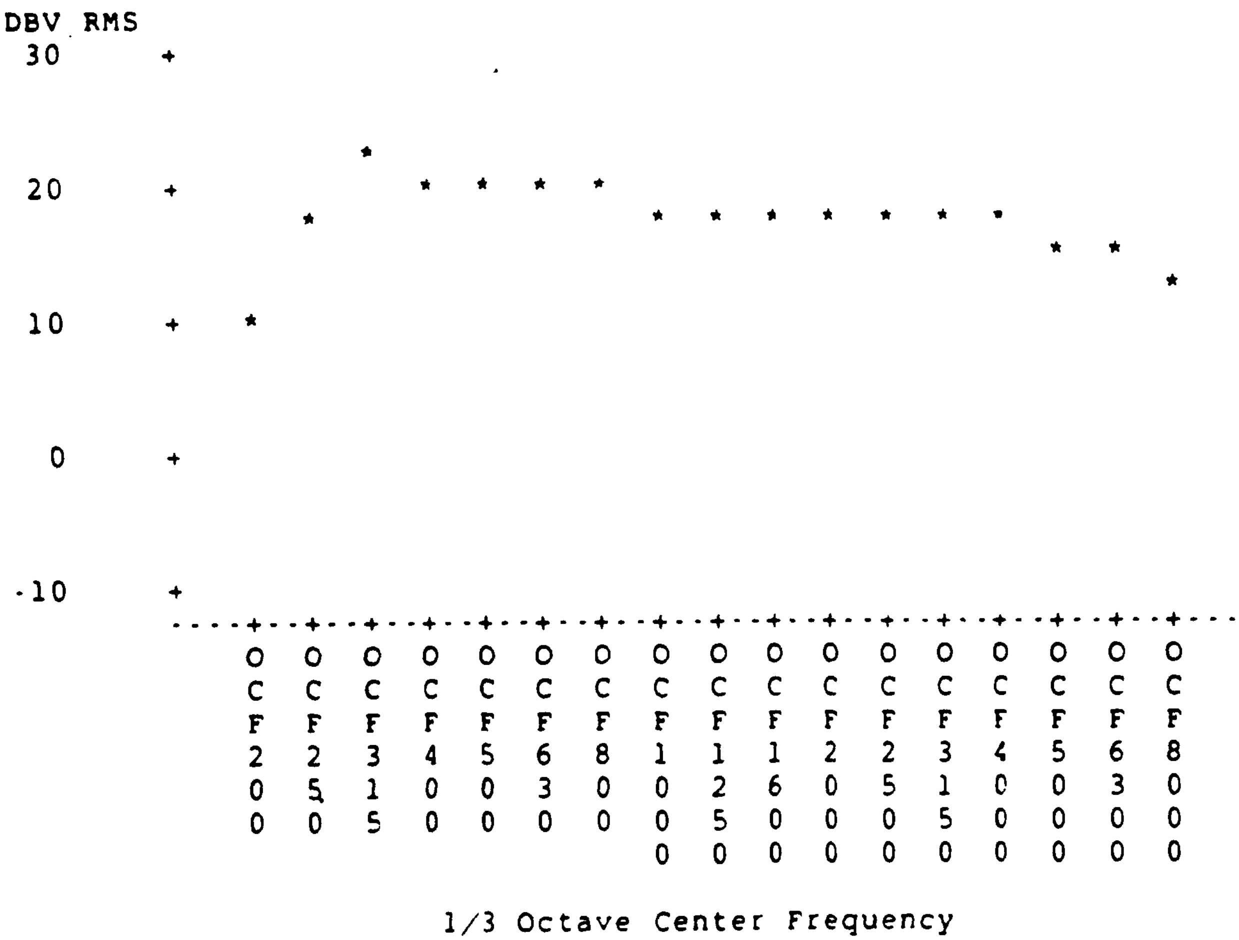
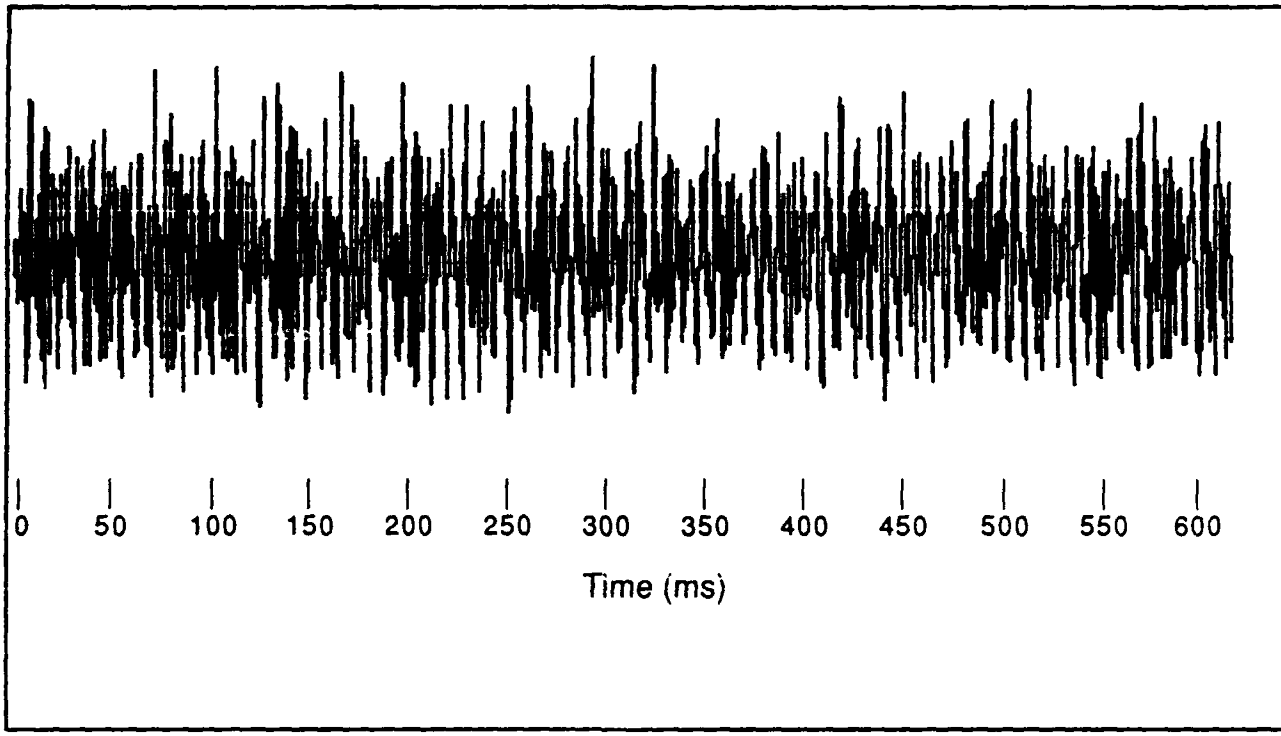




Rifle shot indoors

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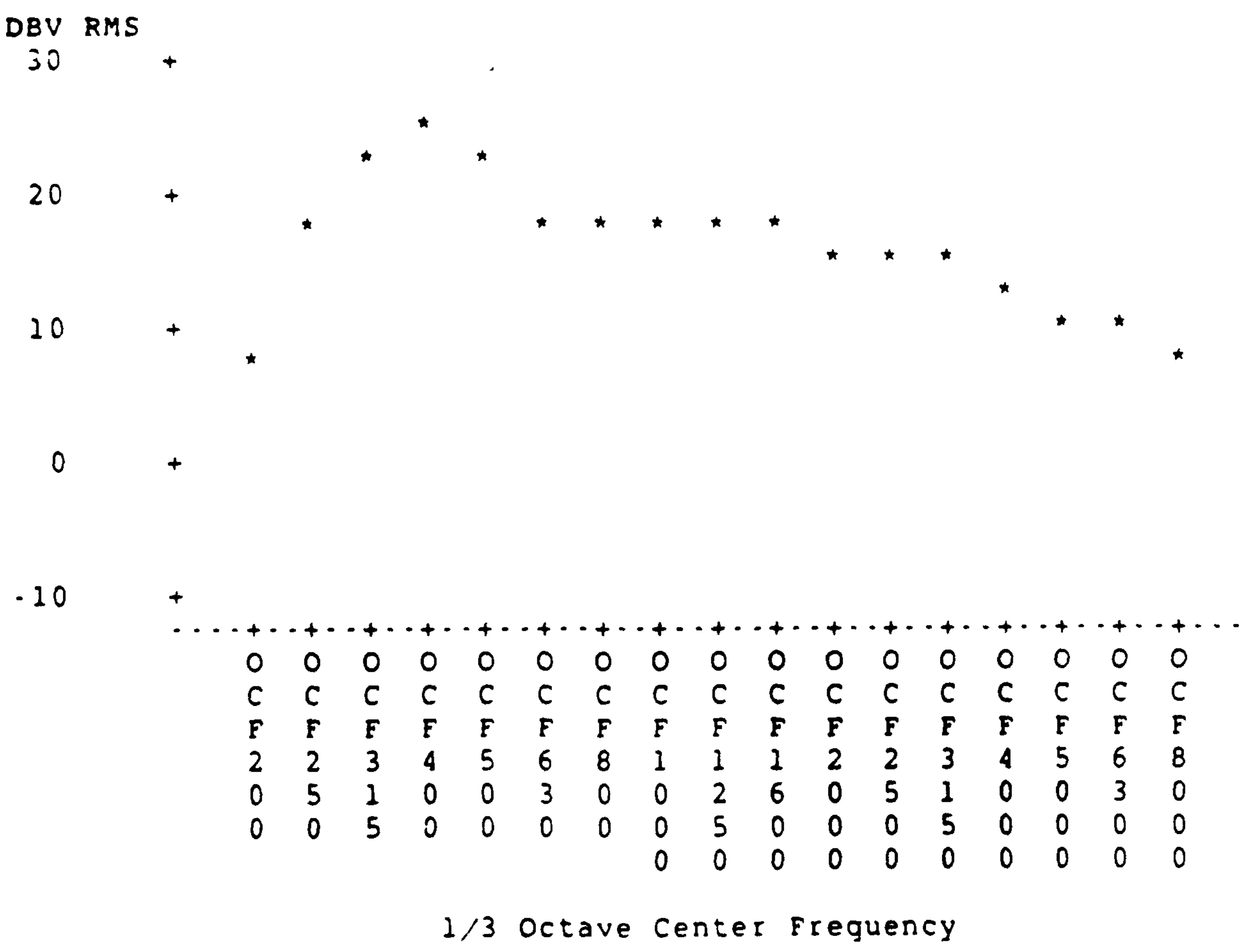
Lawn mower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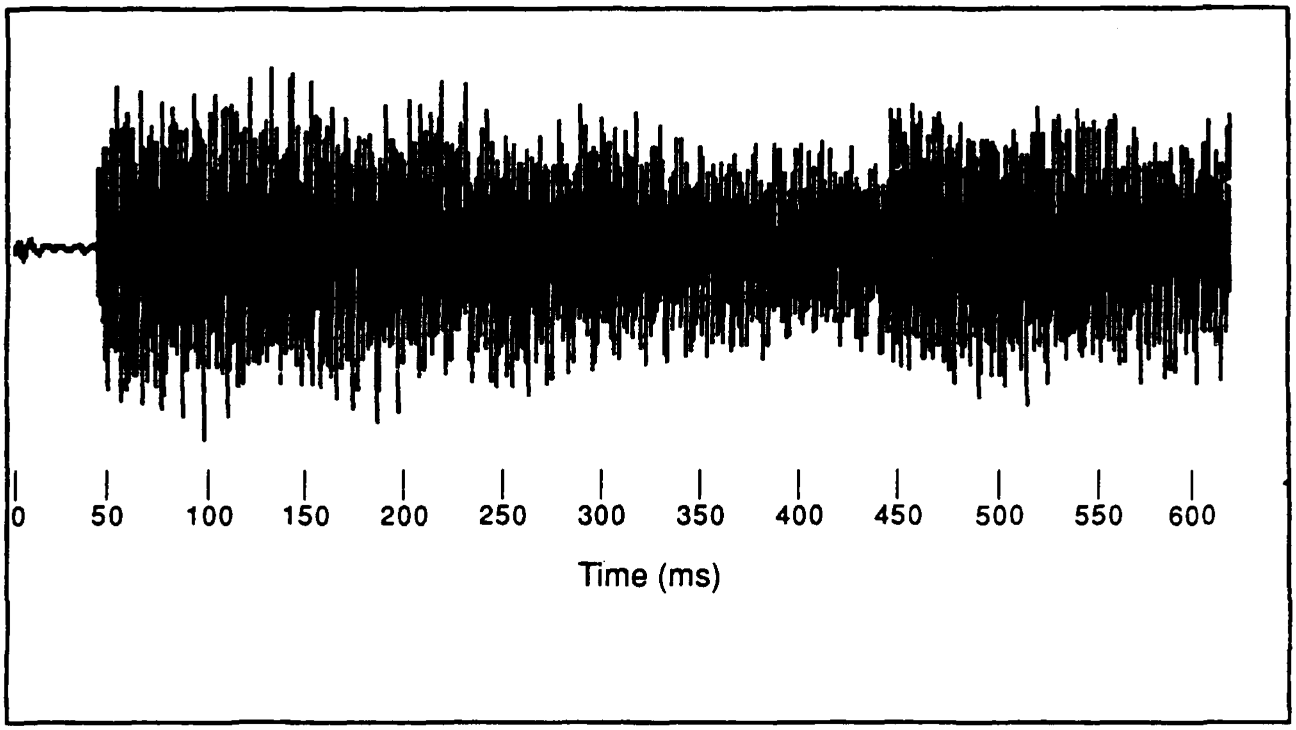
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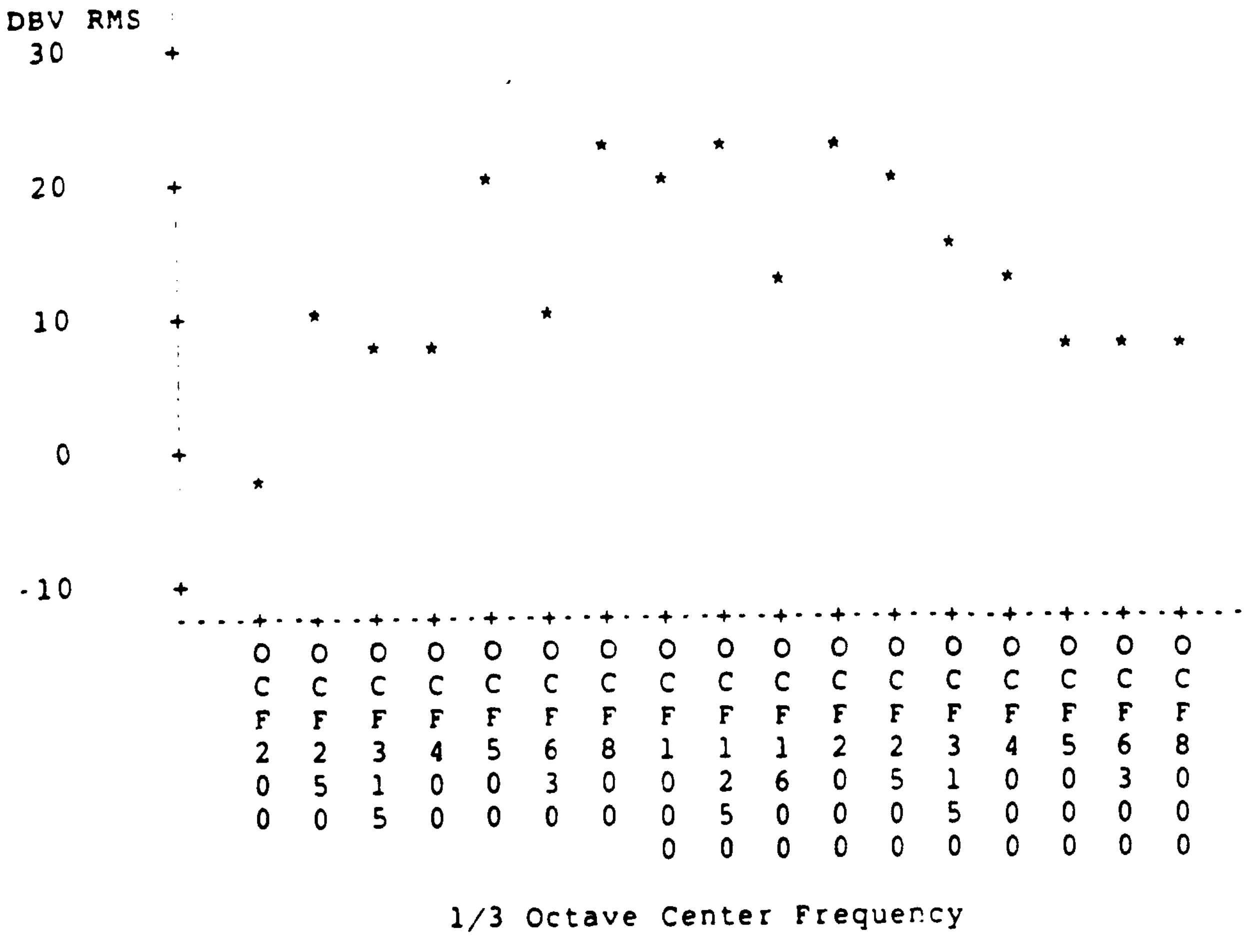
Church bell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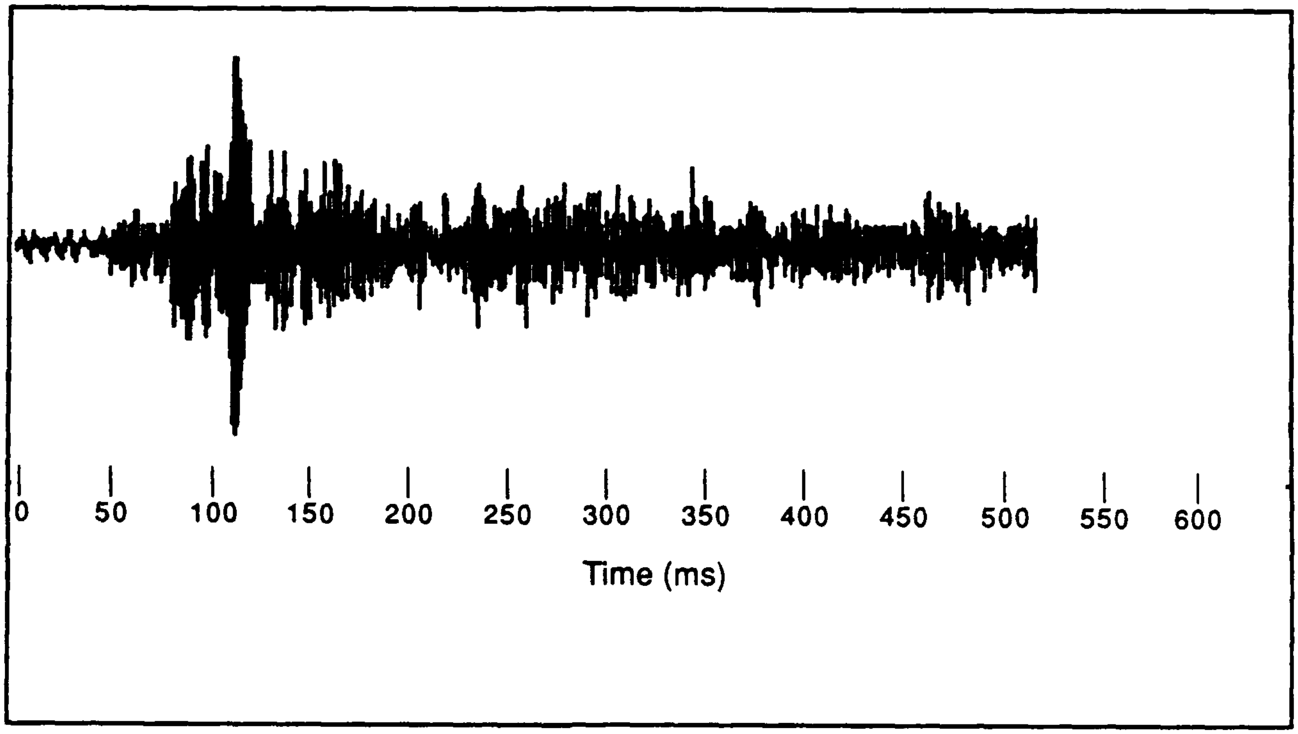
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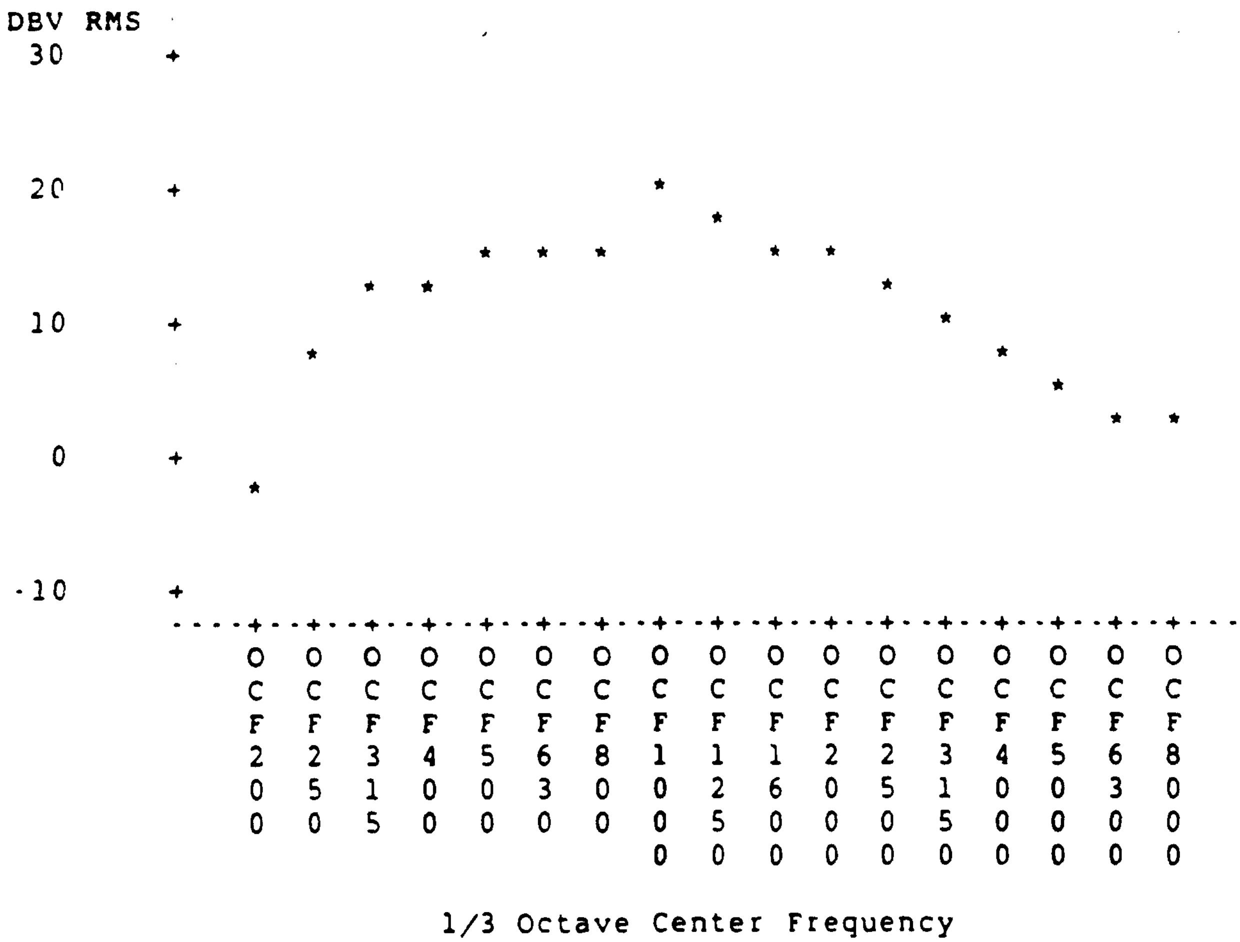
Oar rowing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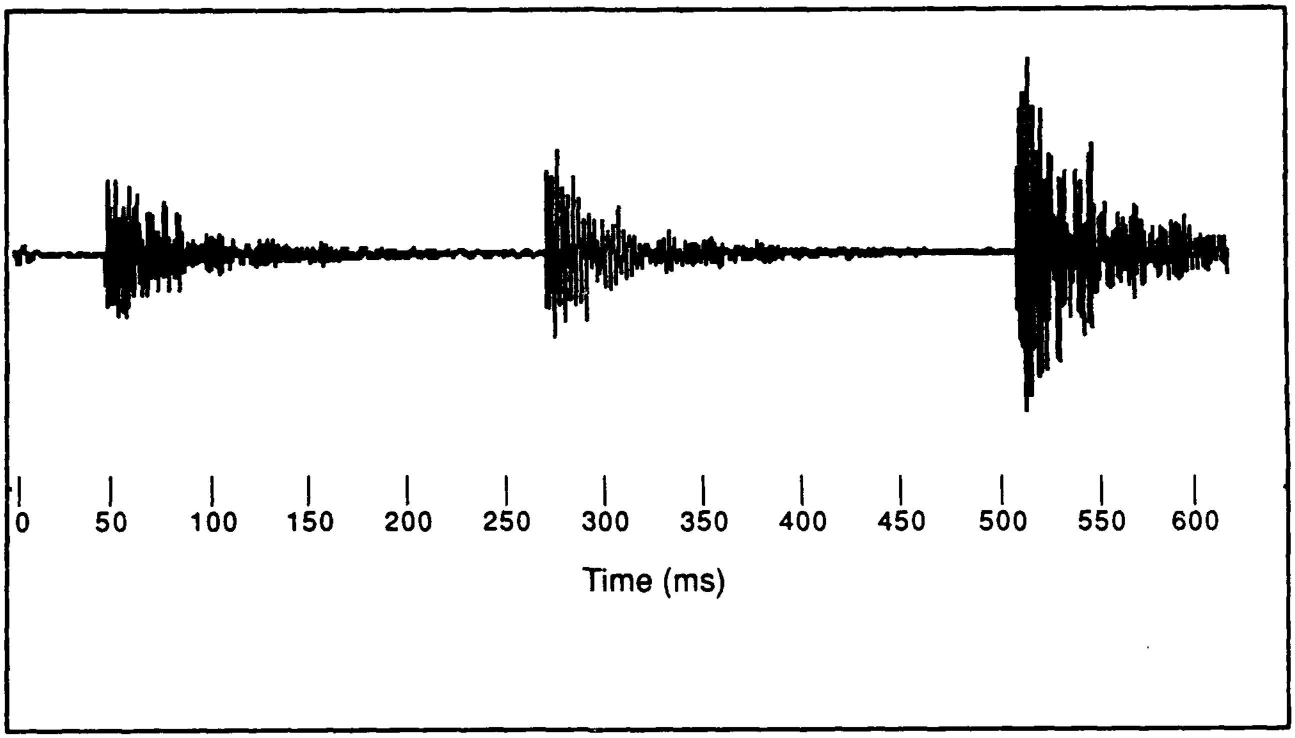
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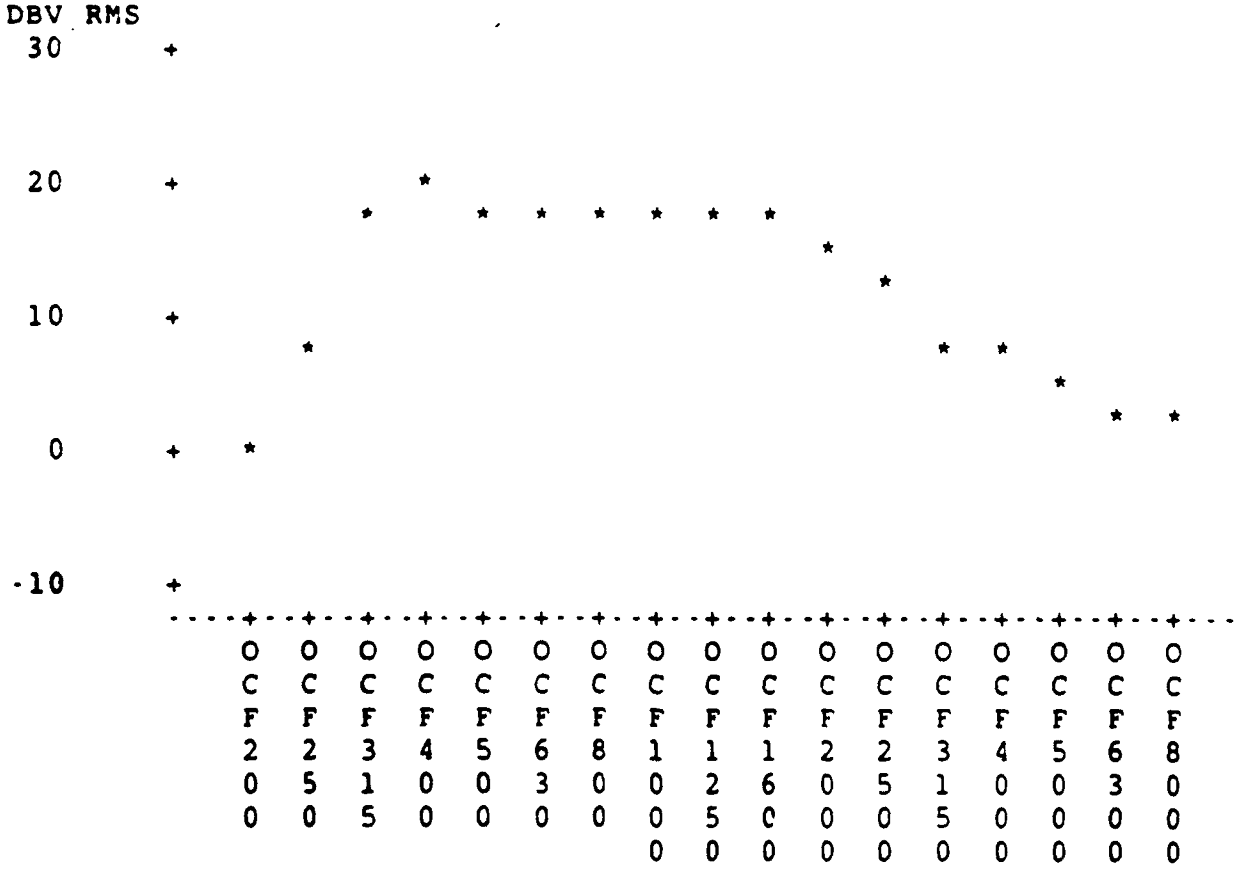
Door knock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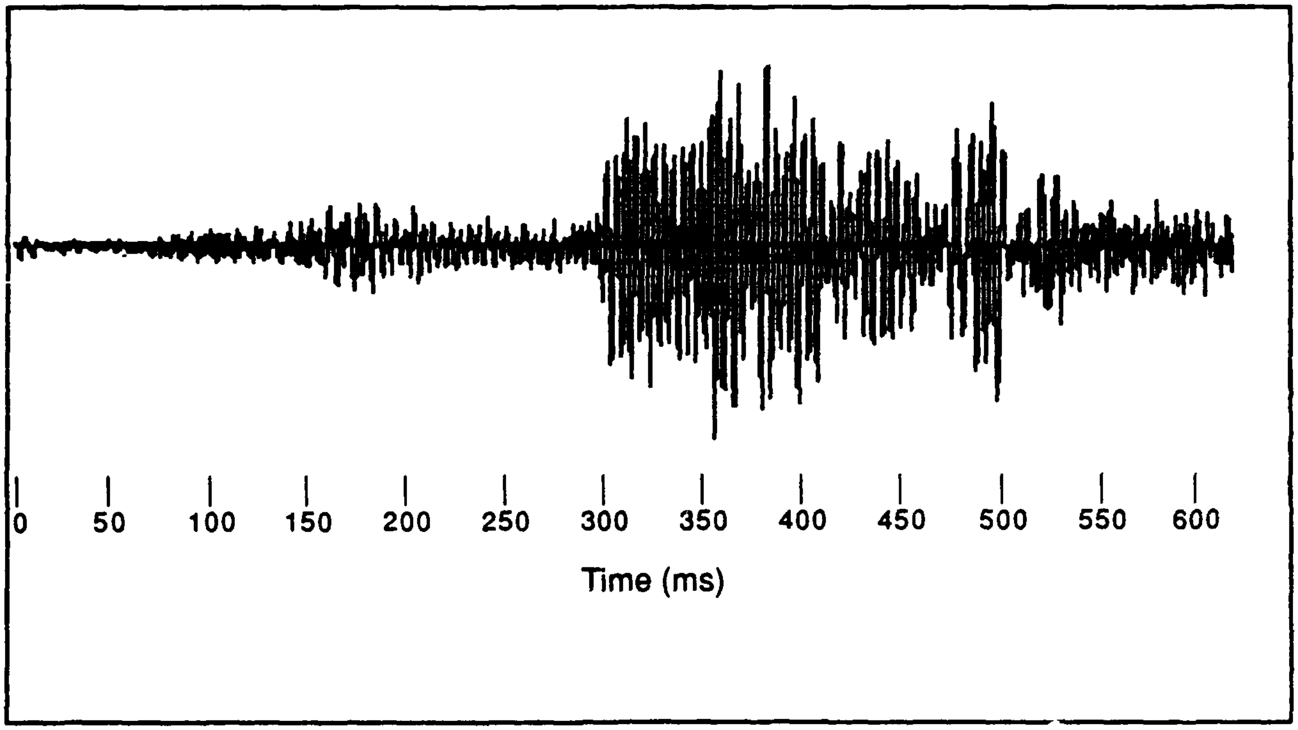
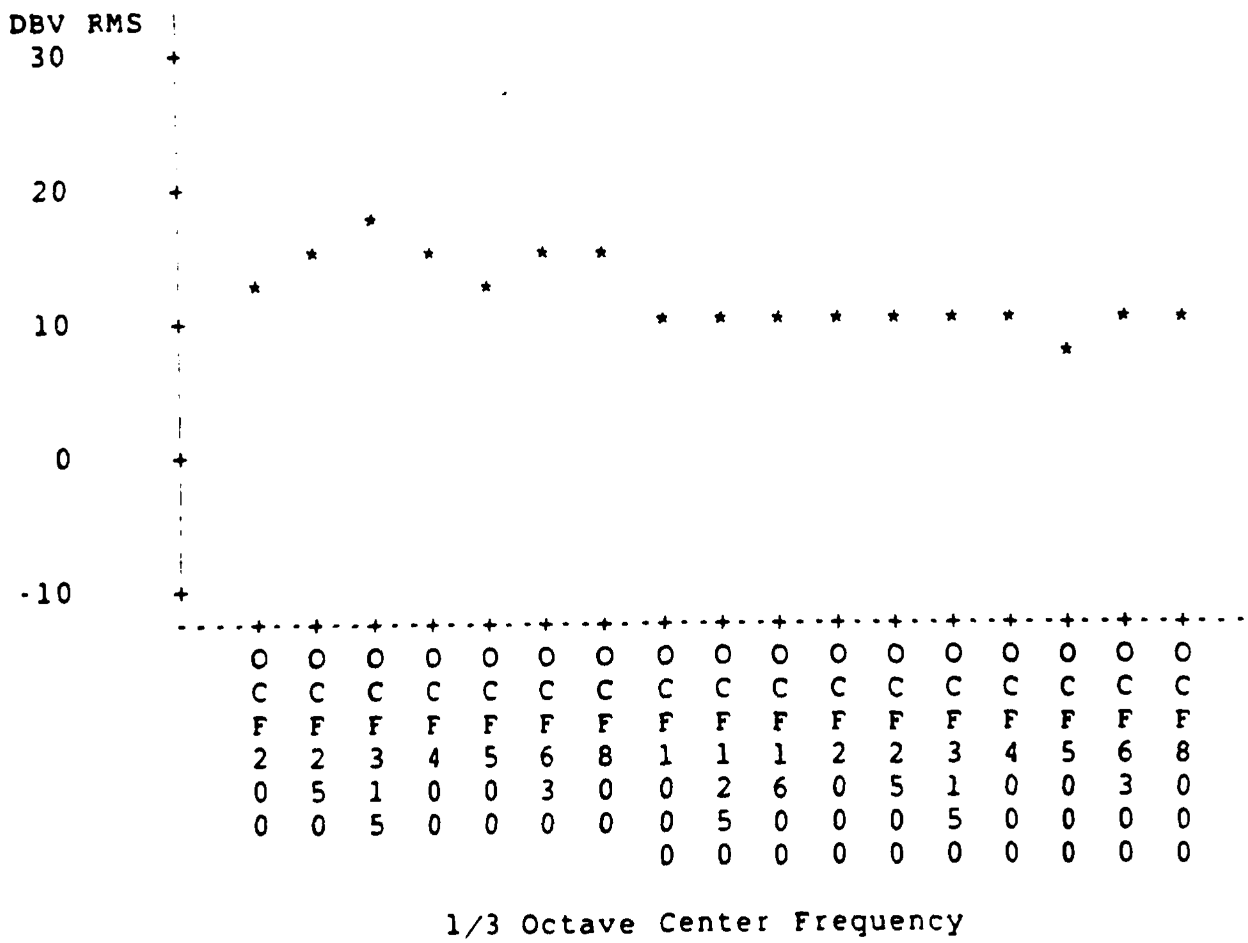
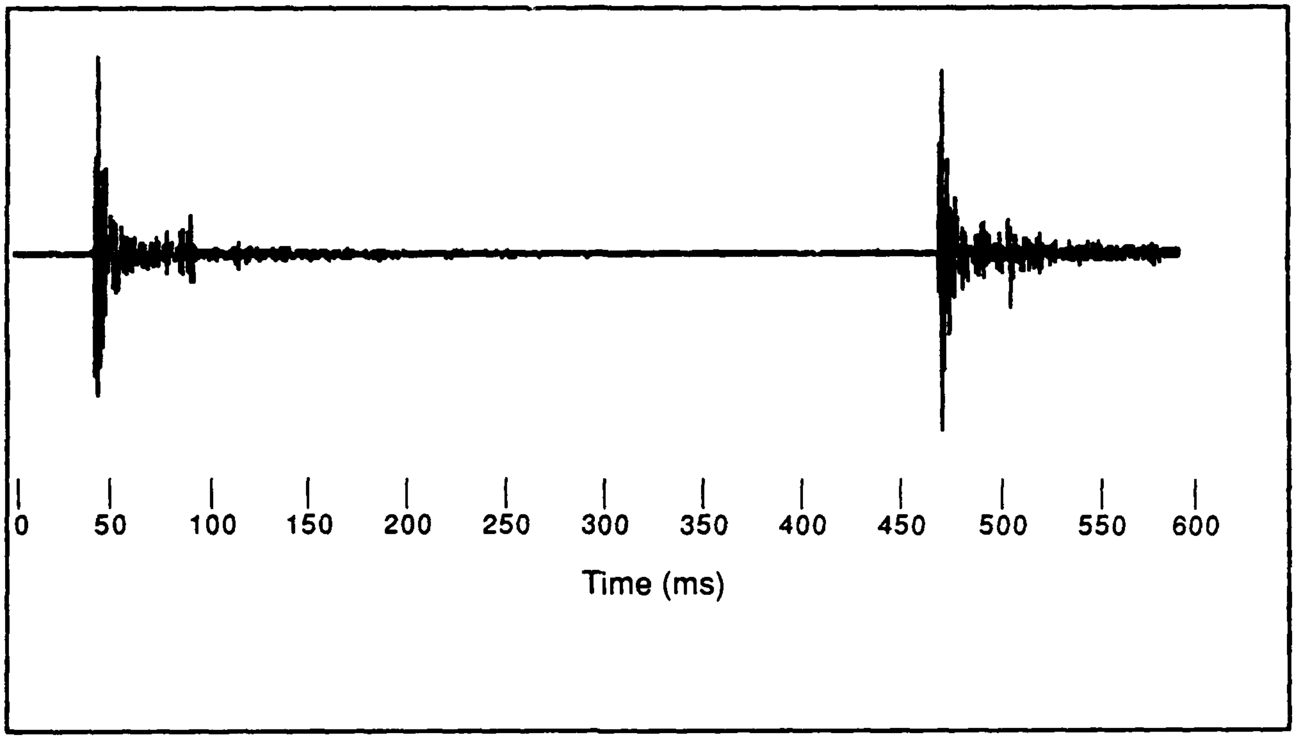


Toilet flush

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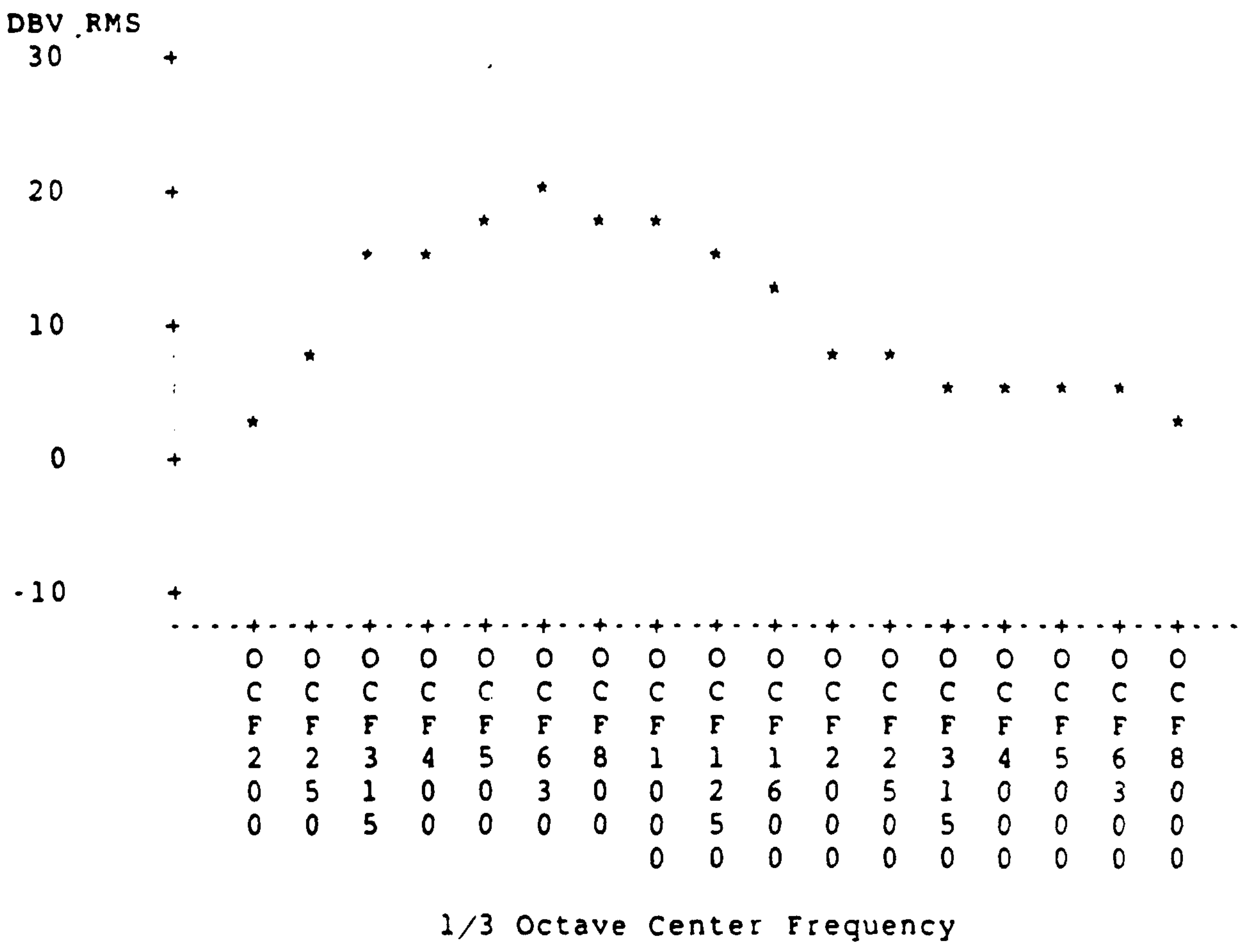
Footsteps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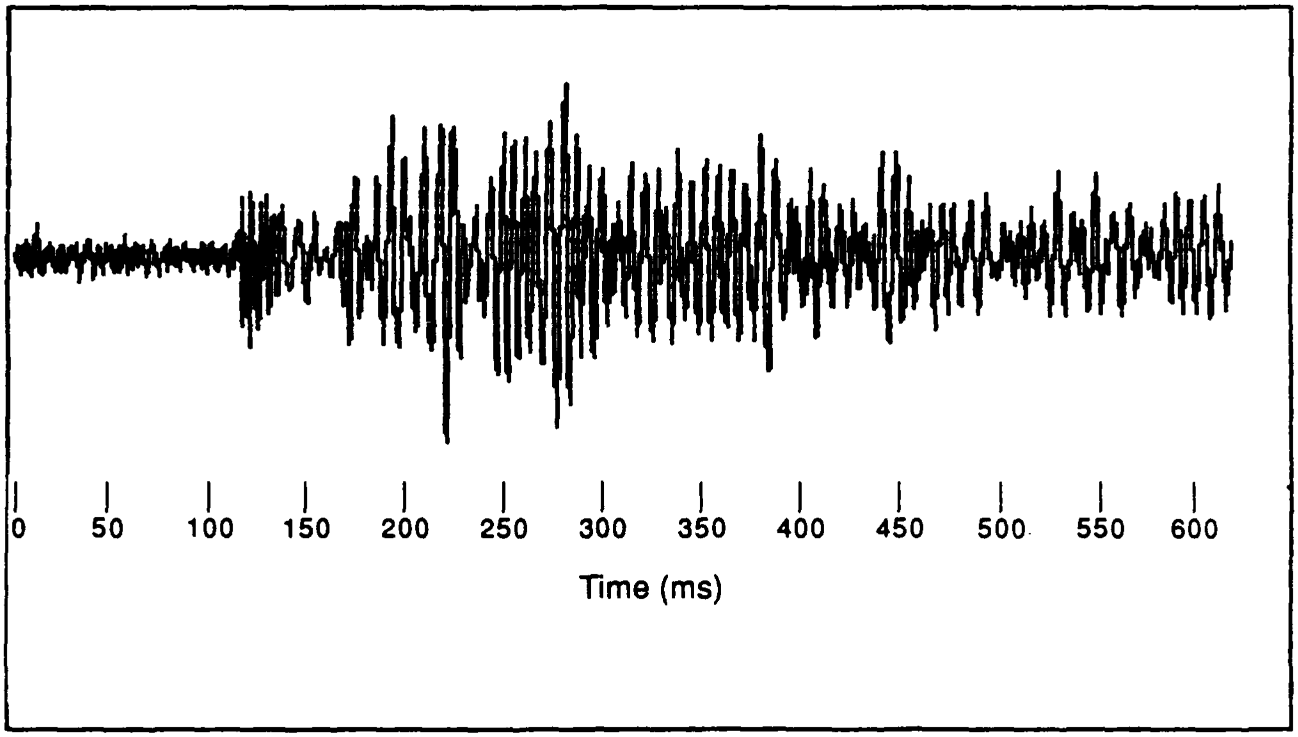
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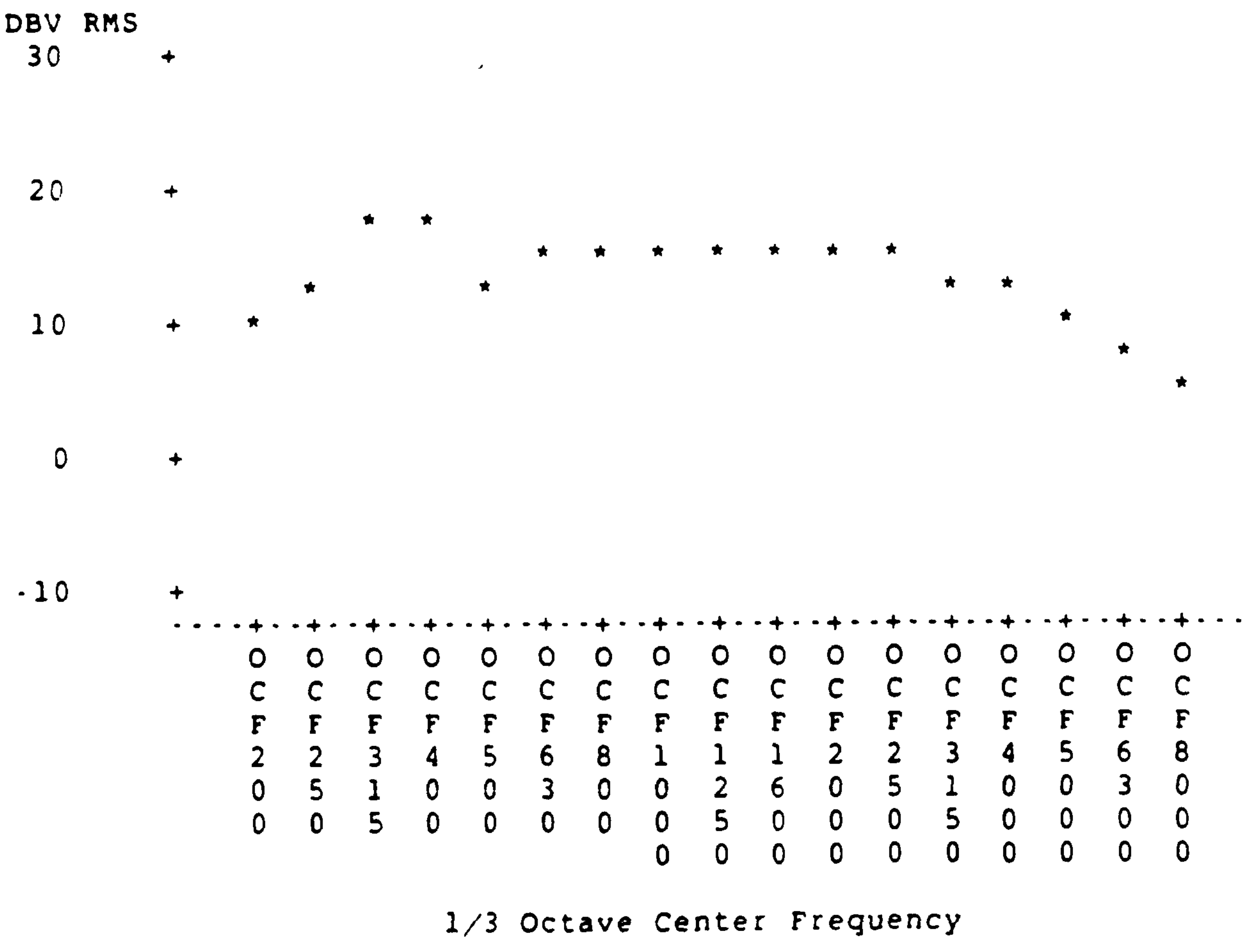
Time (ms)

Fireworks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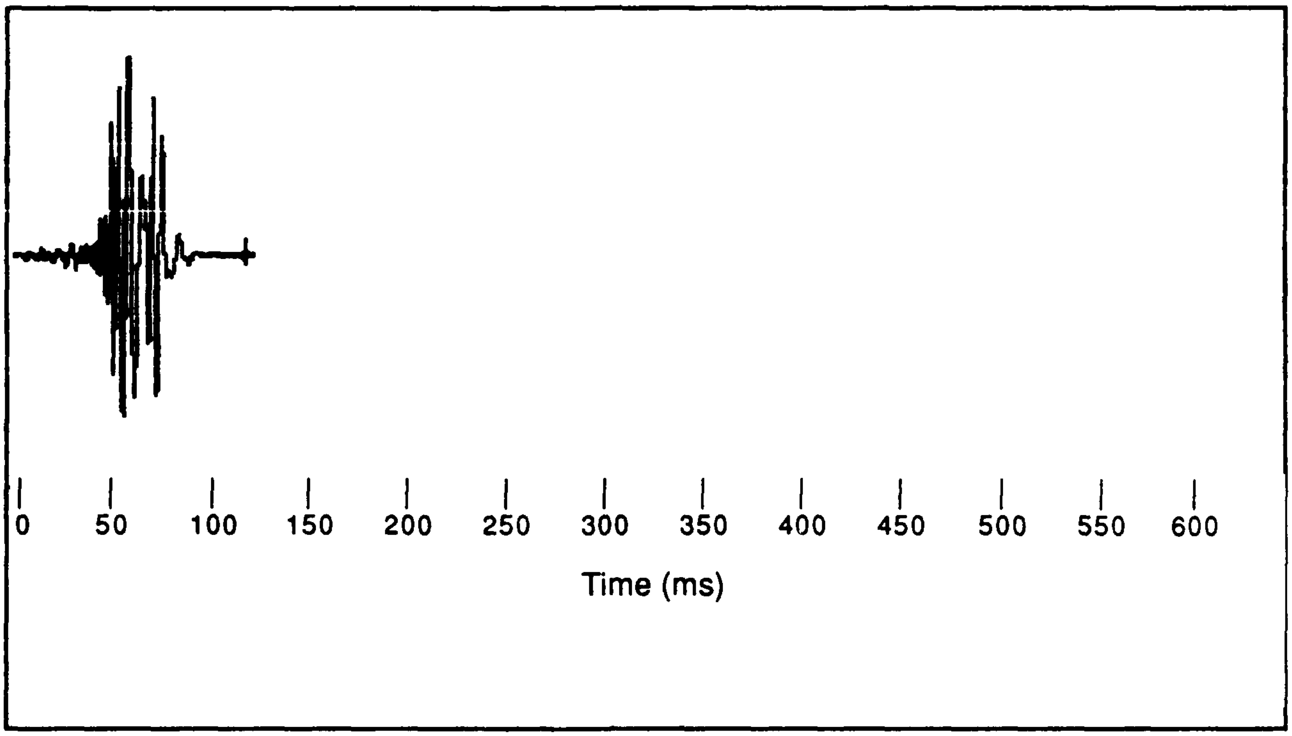
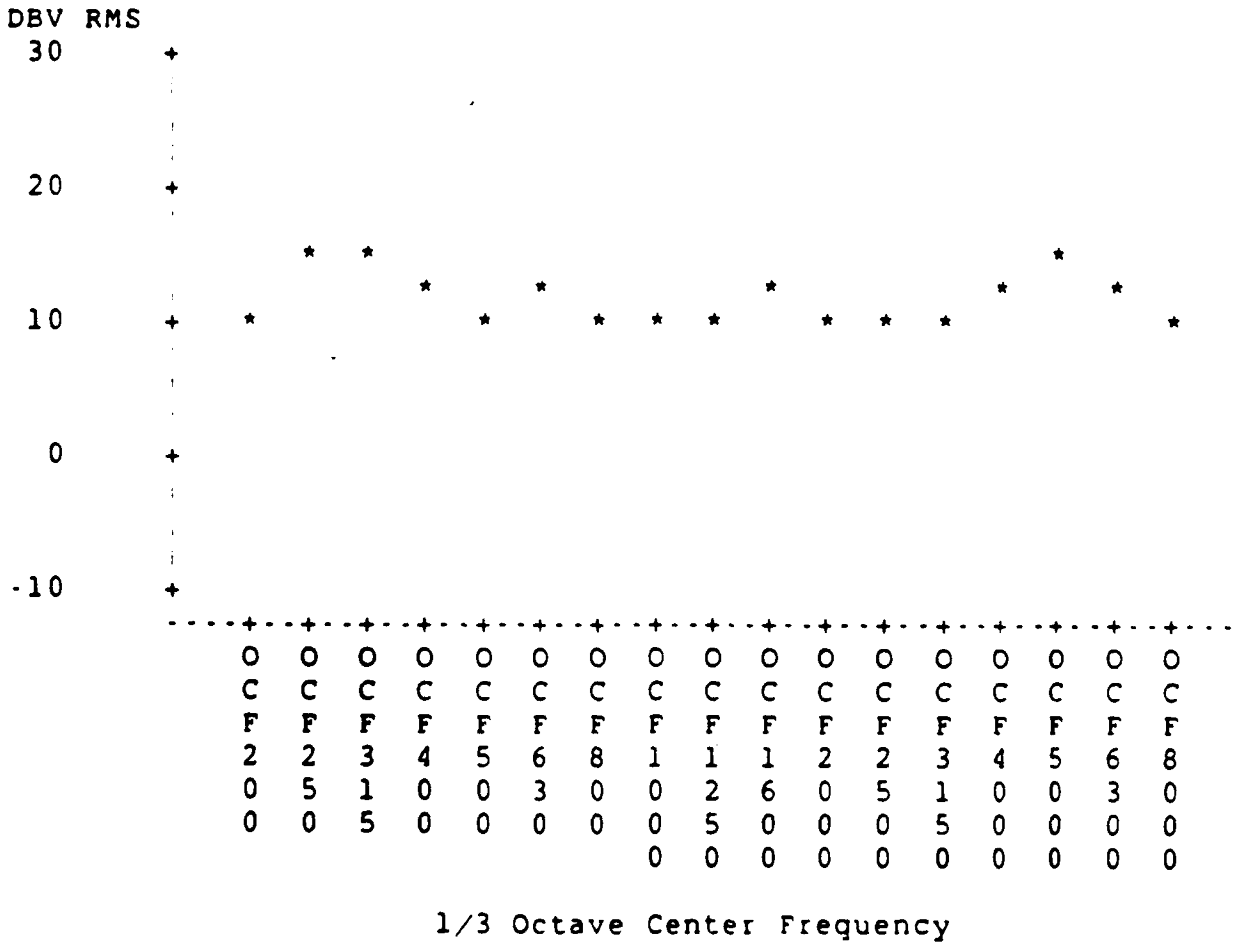
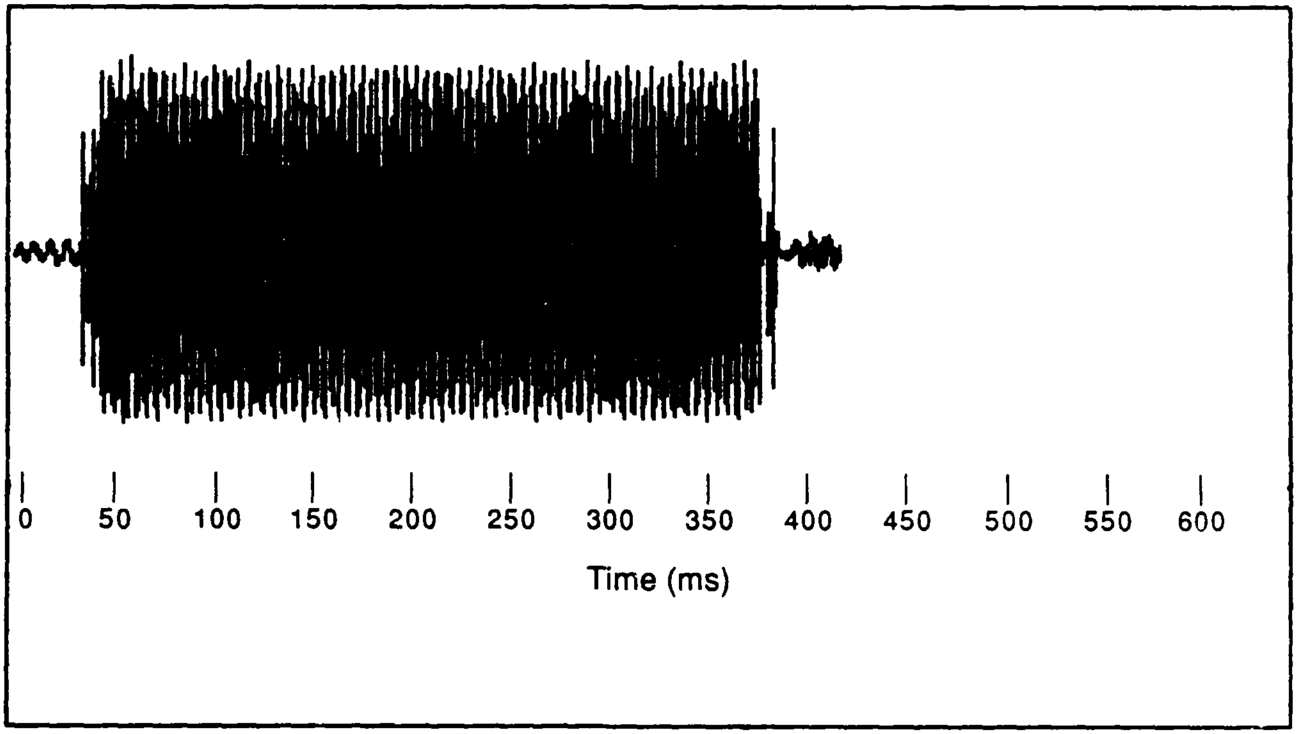
1/3 Octave Center Frequency



Cigarette lighter





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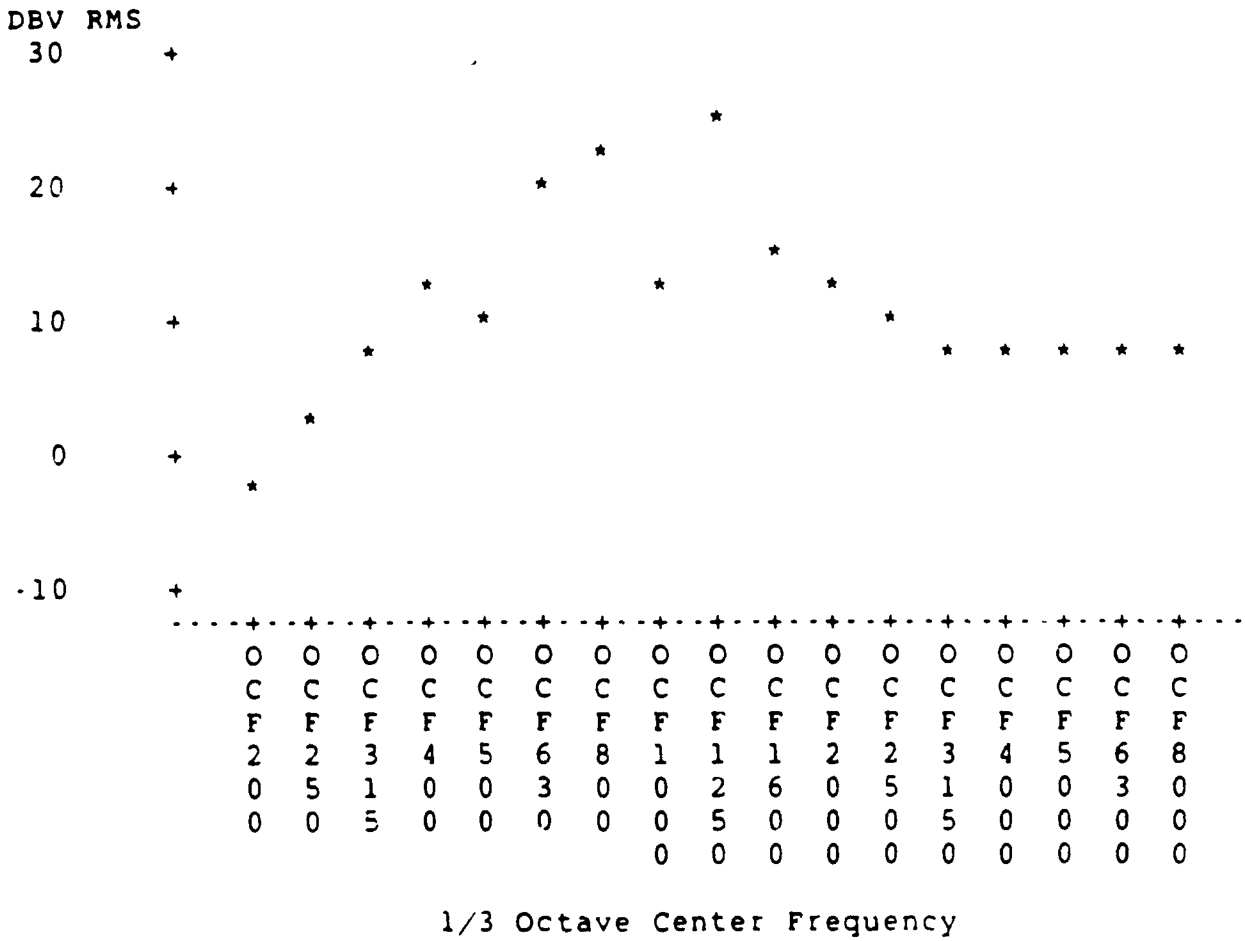
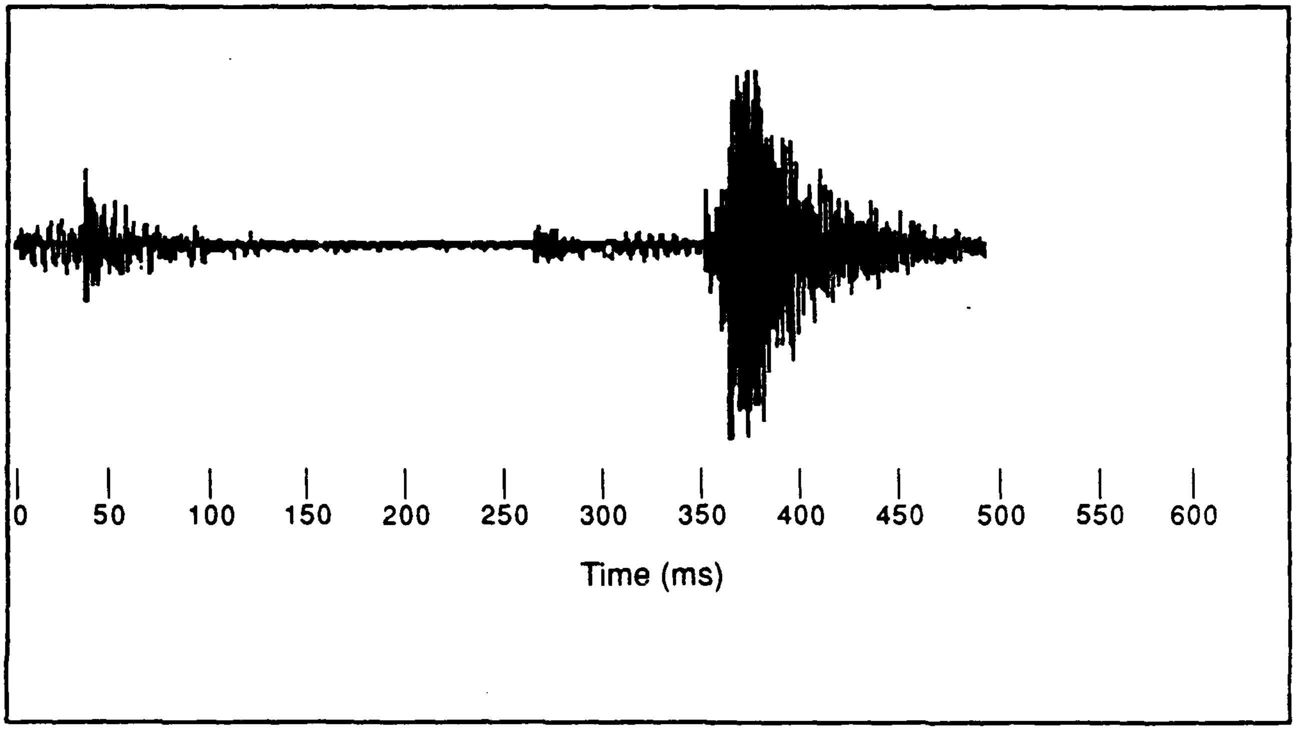
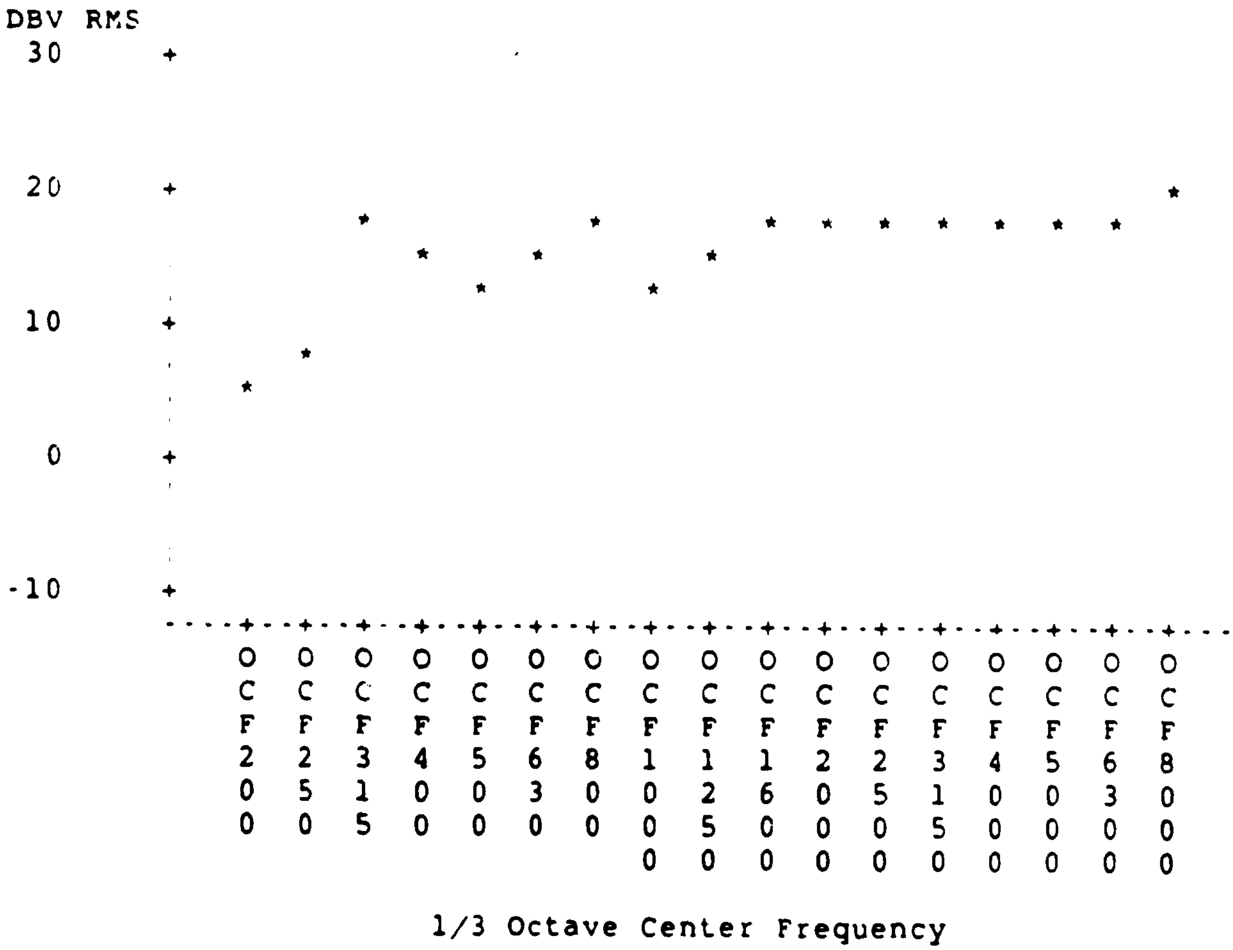
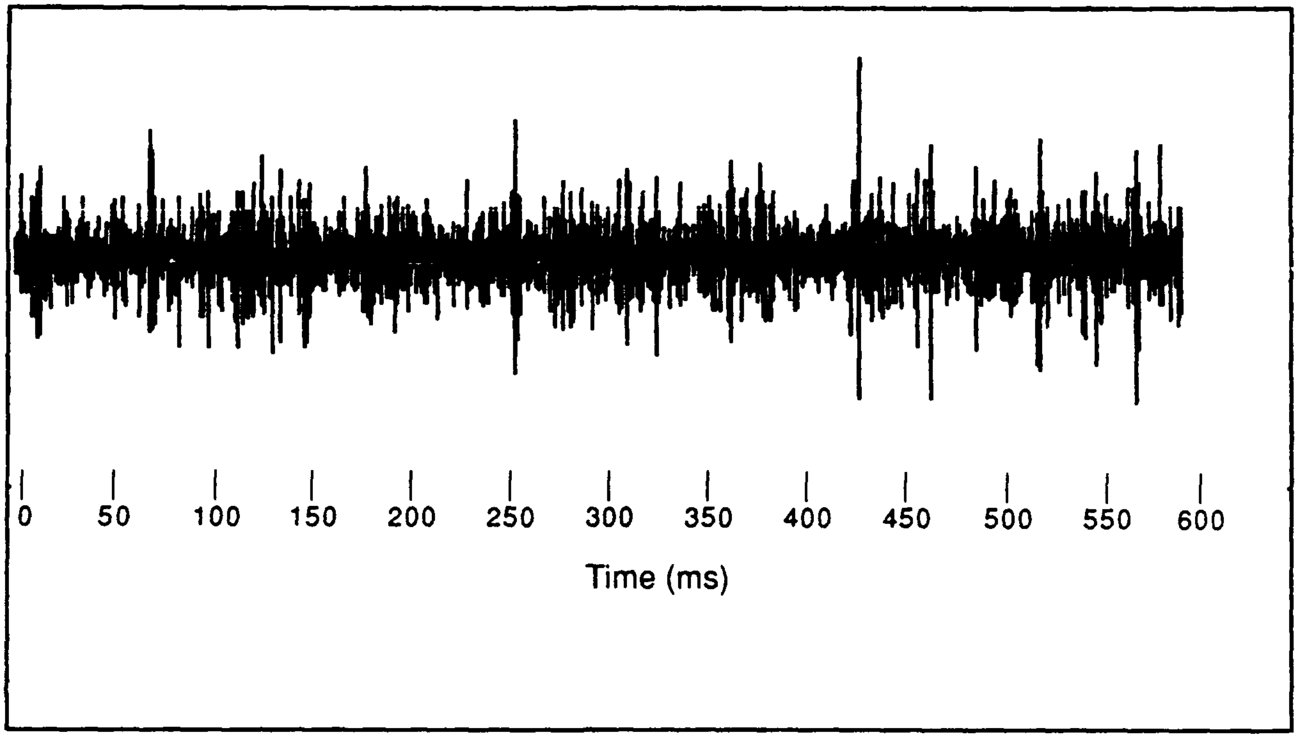


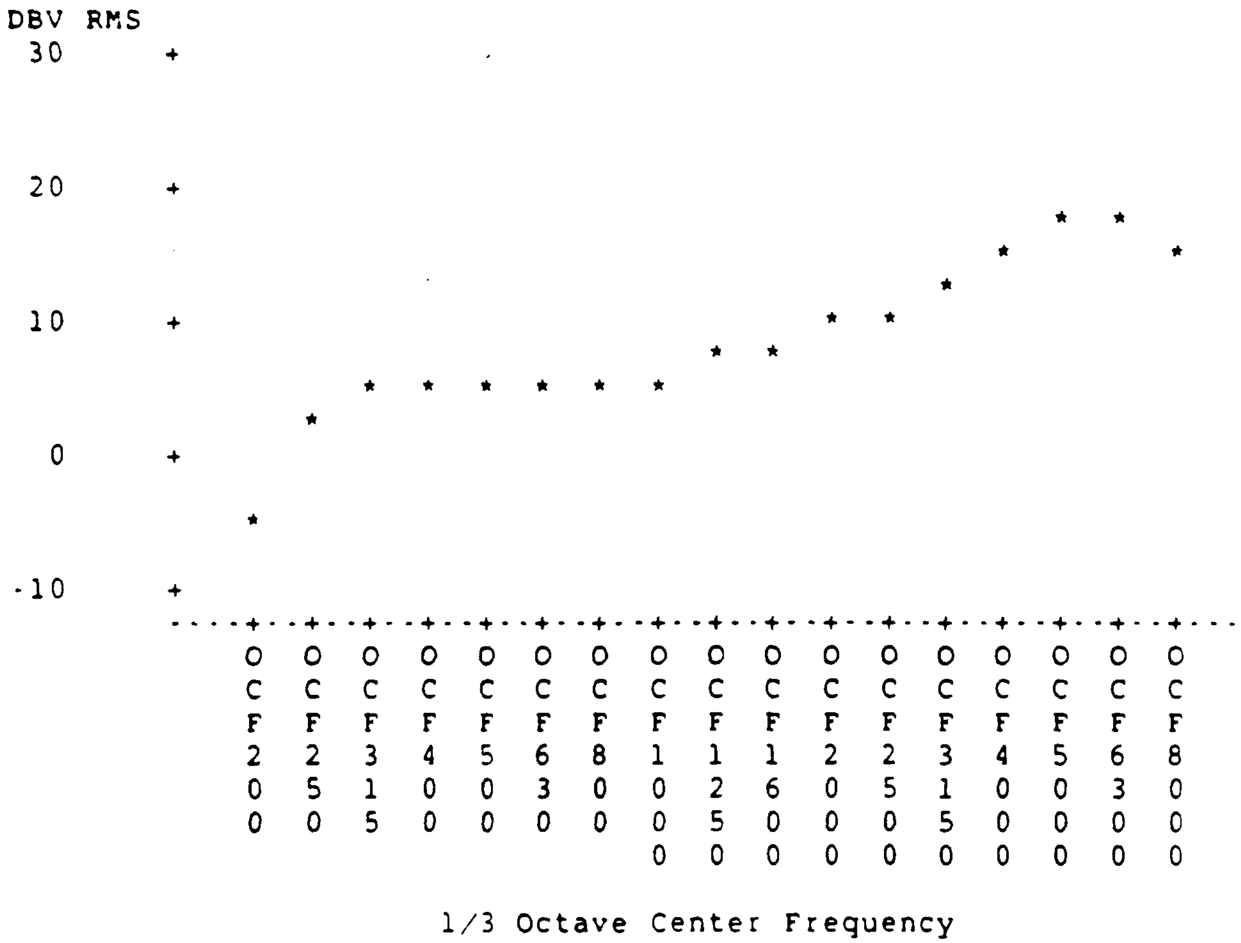


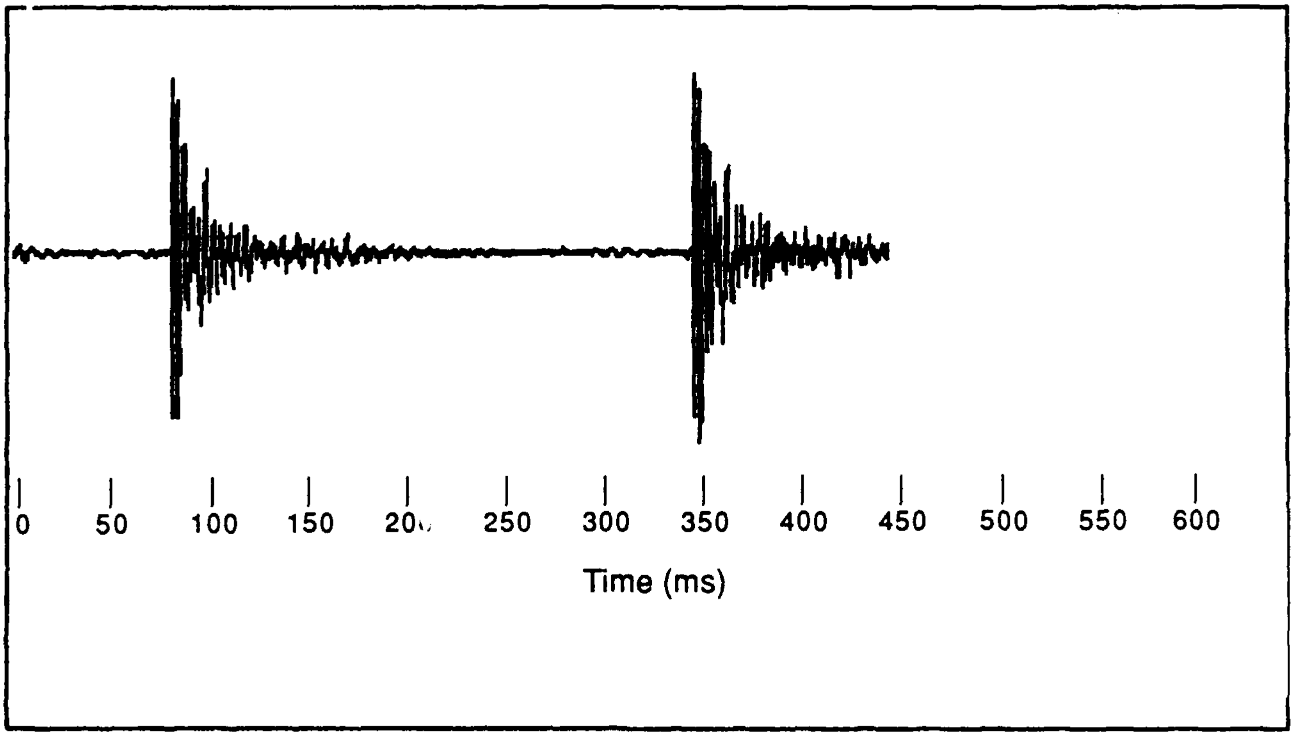
Door opening





Bacon frying

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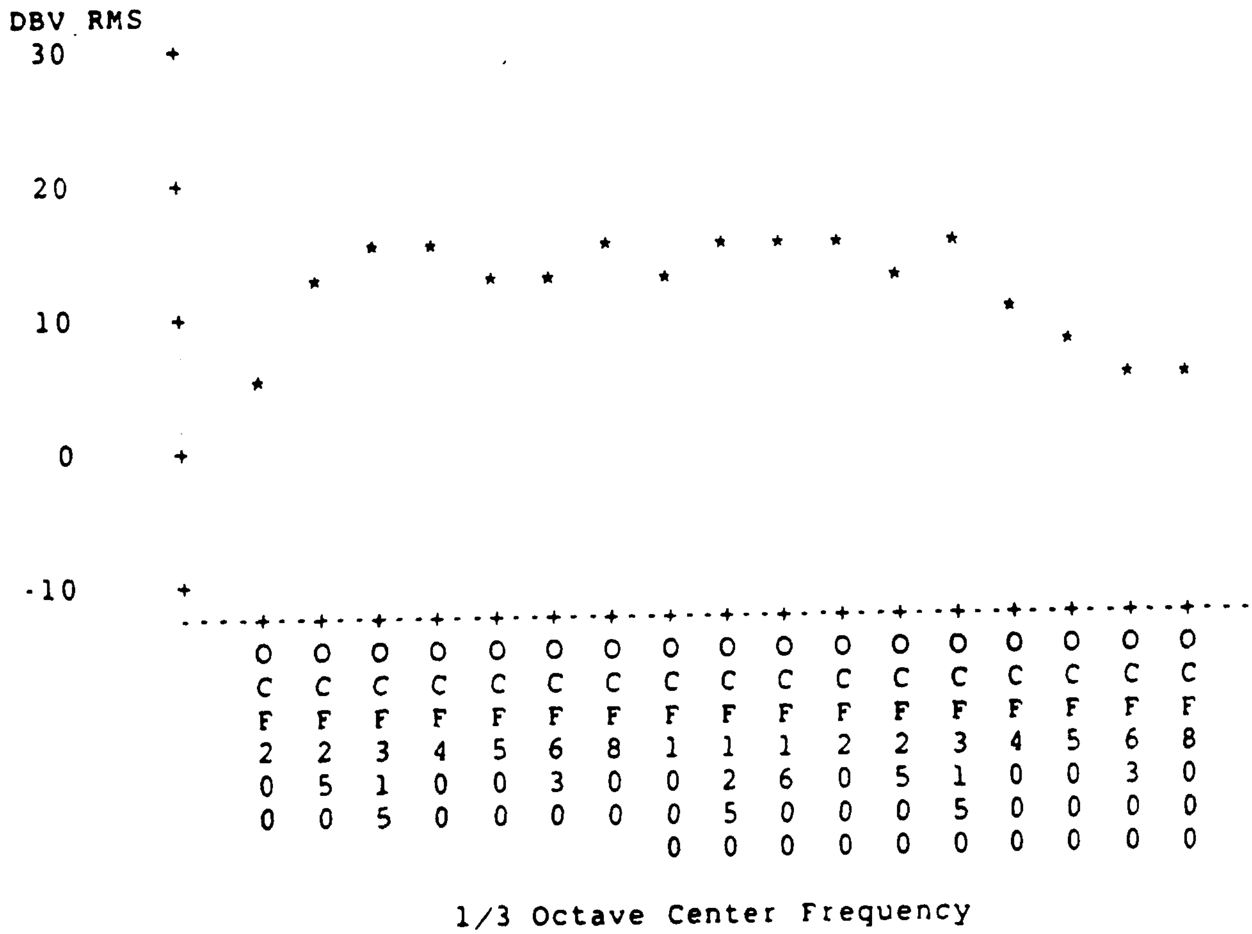
Hammering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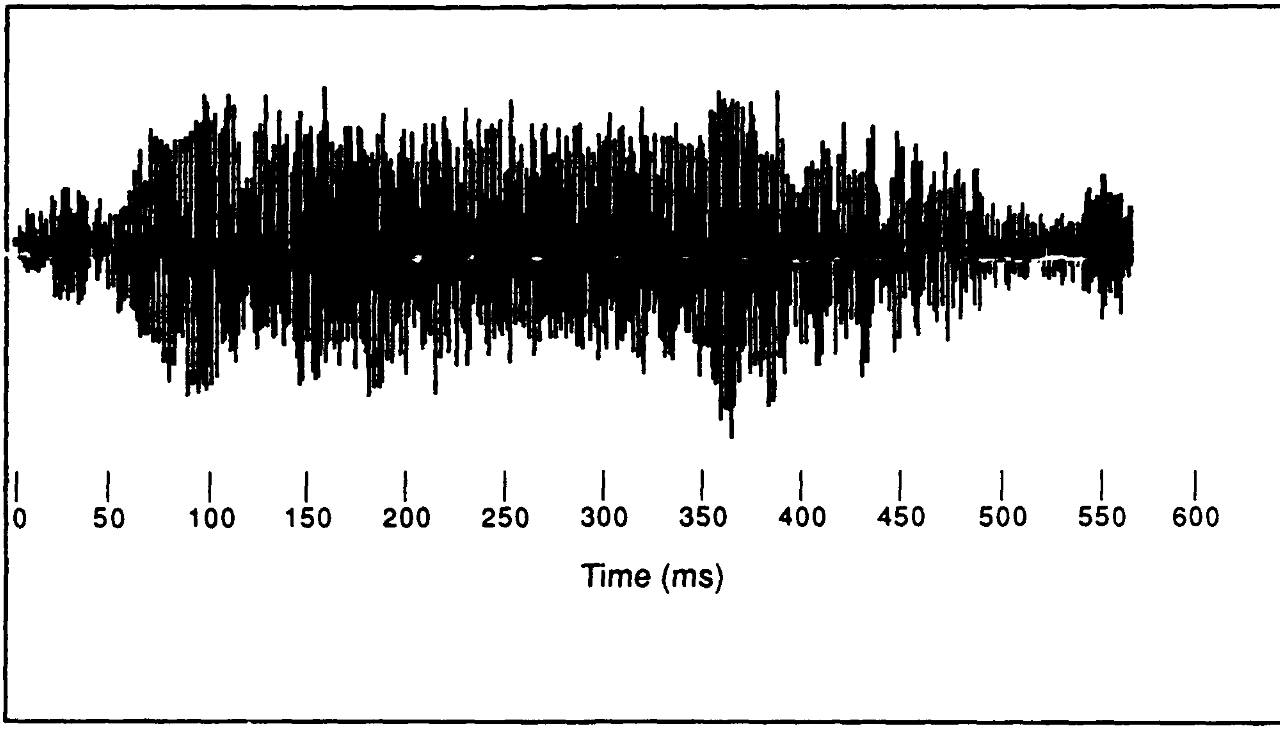
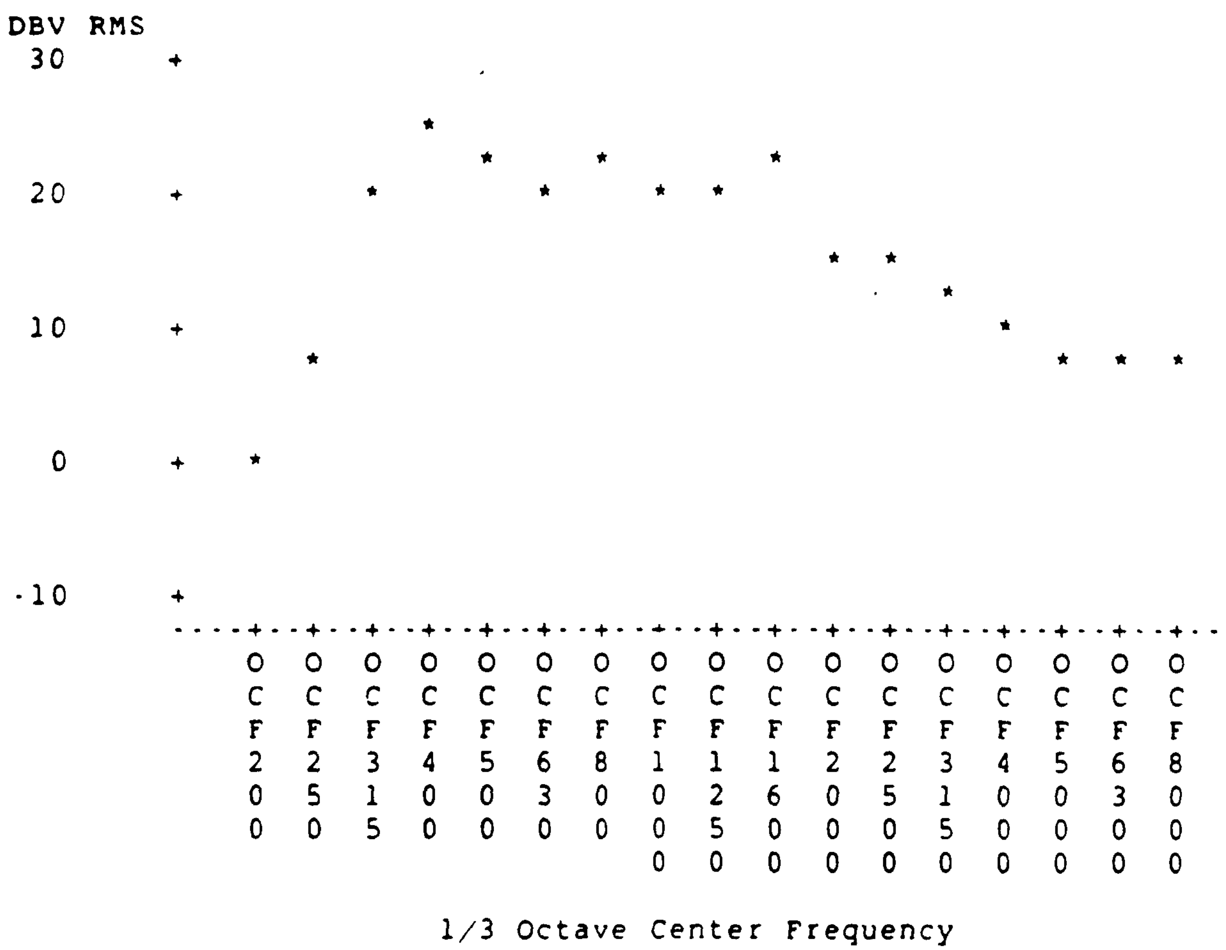
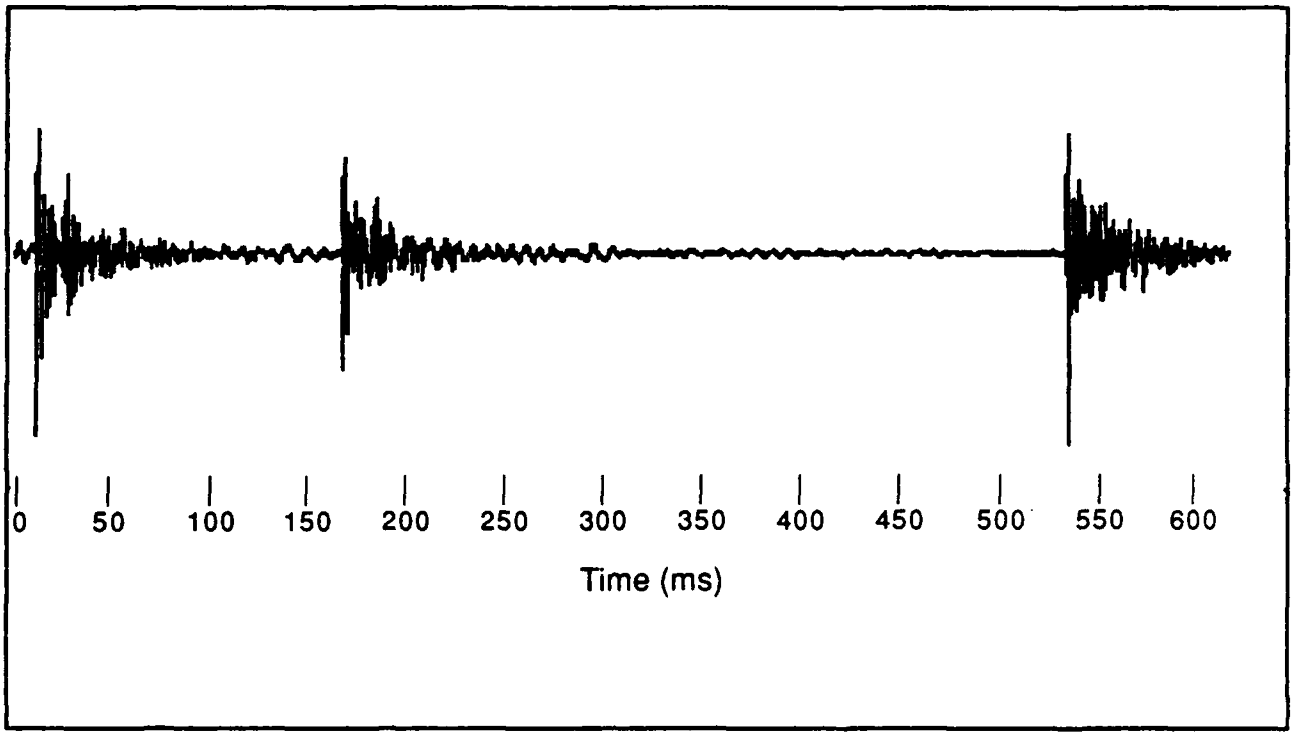
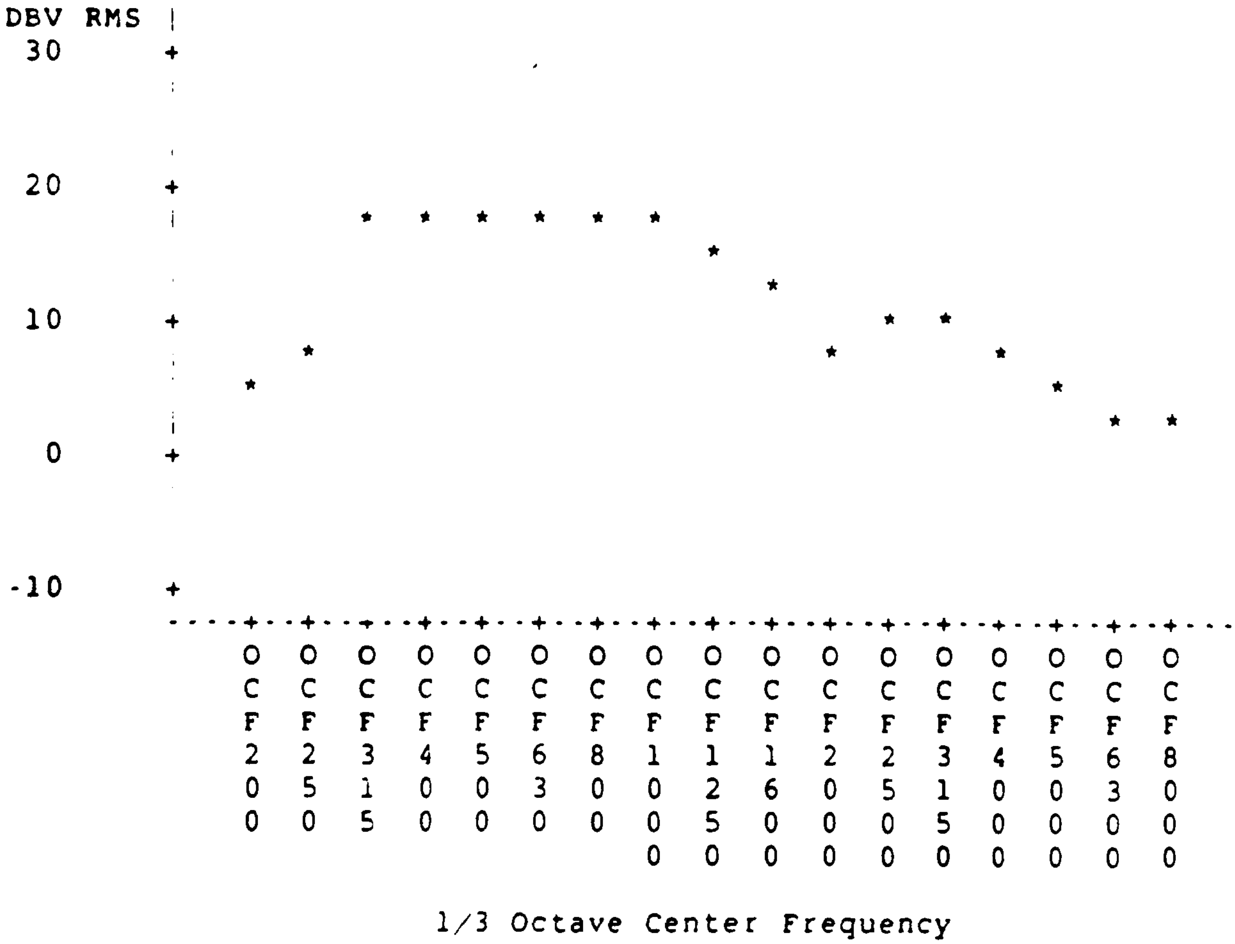


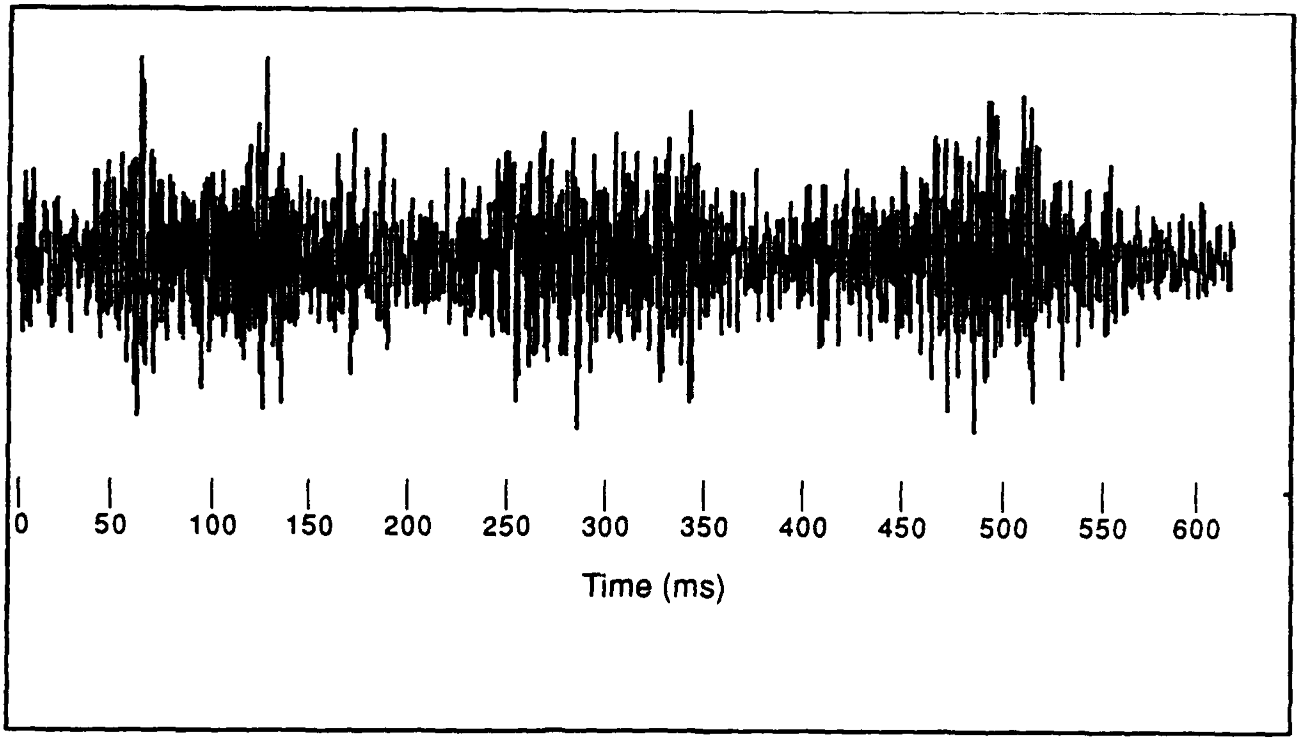
Sub dive horn



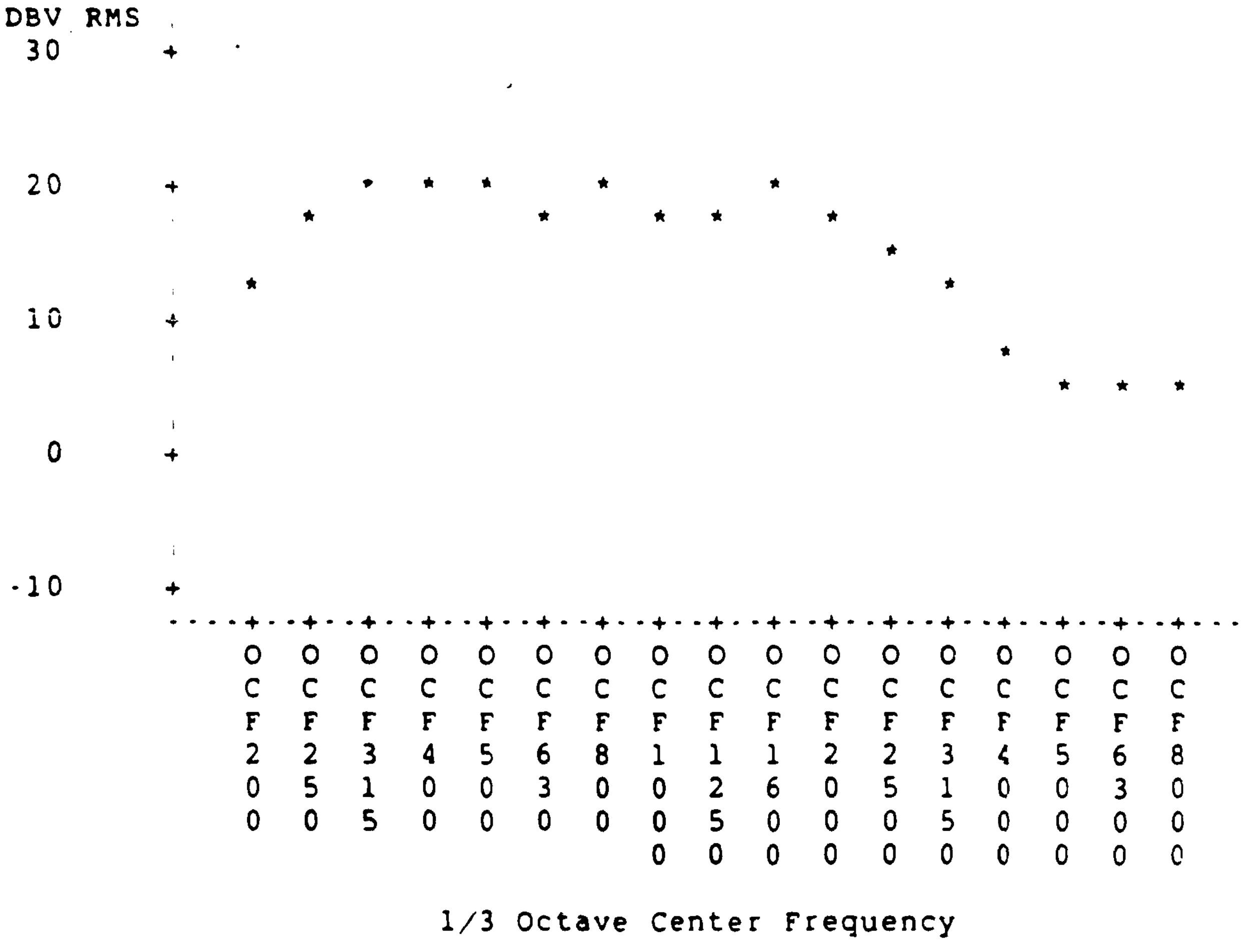


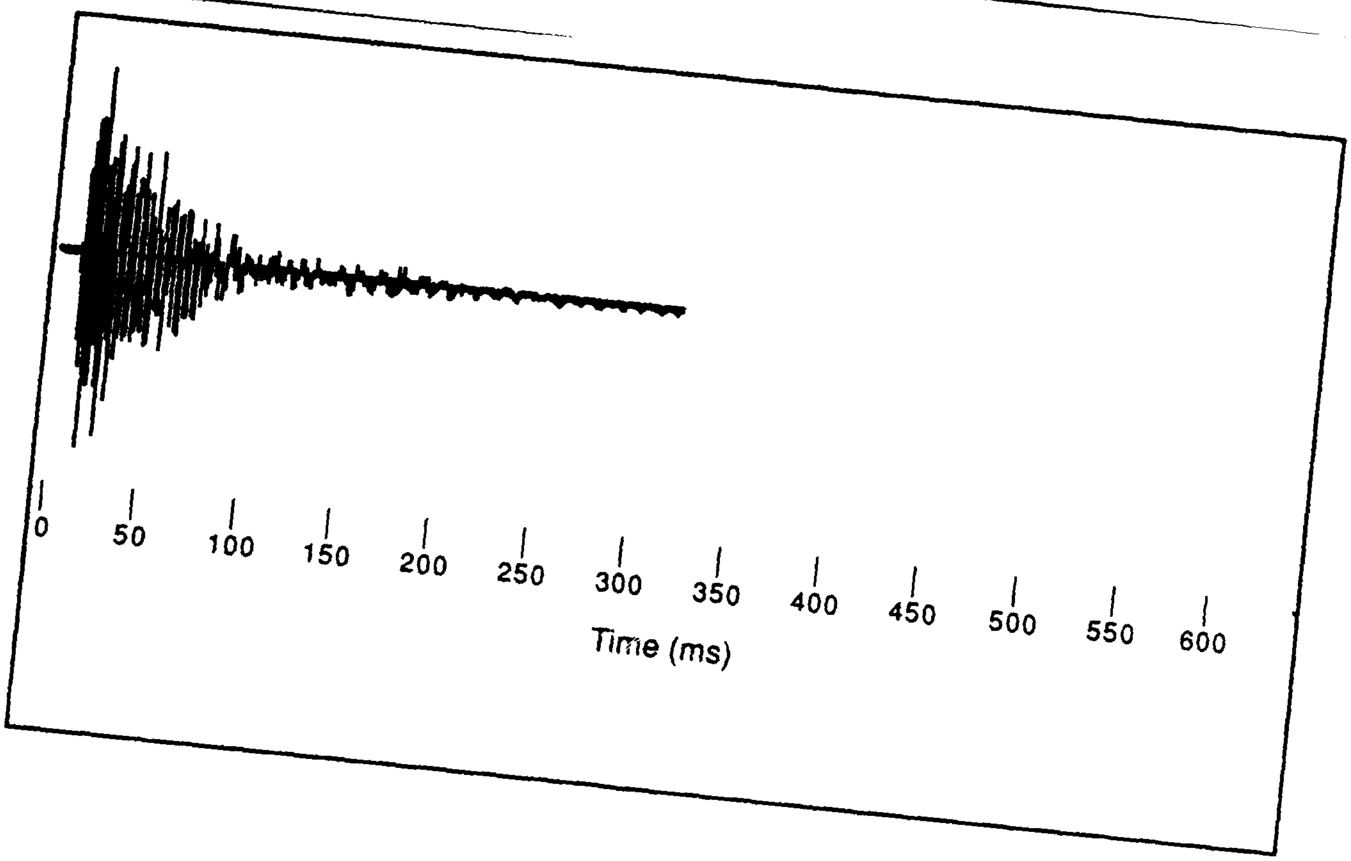
Walking in clogs





Car ignition

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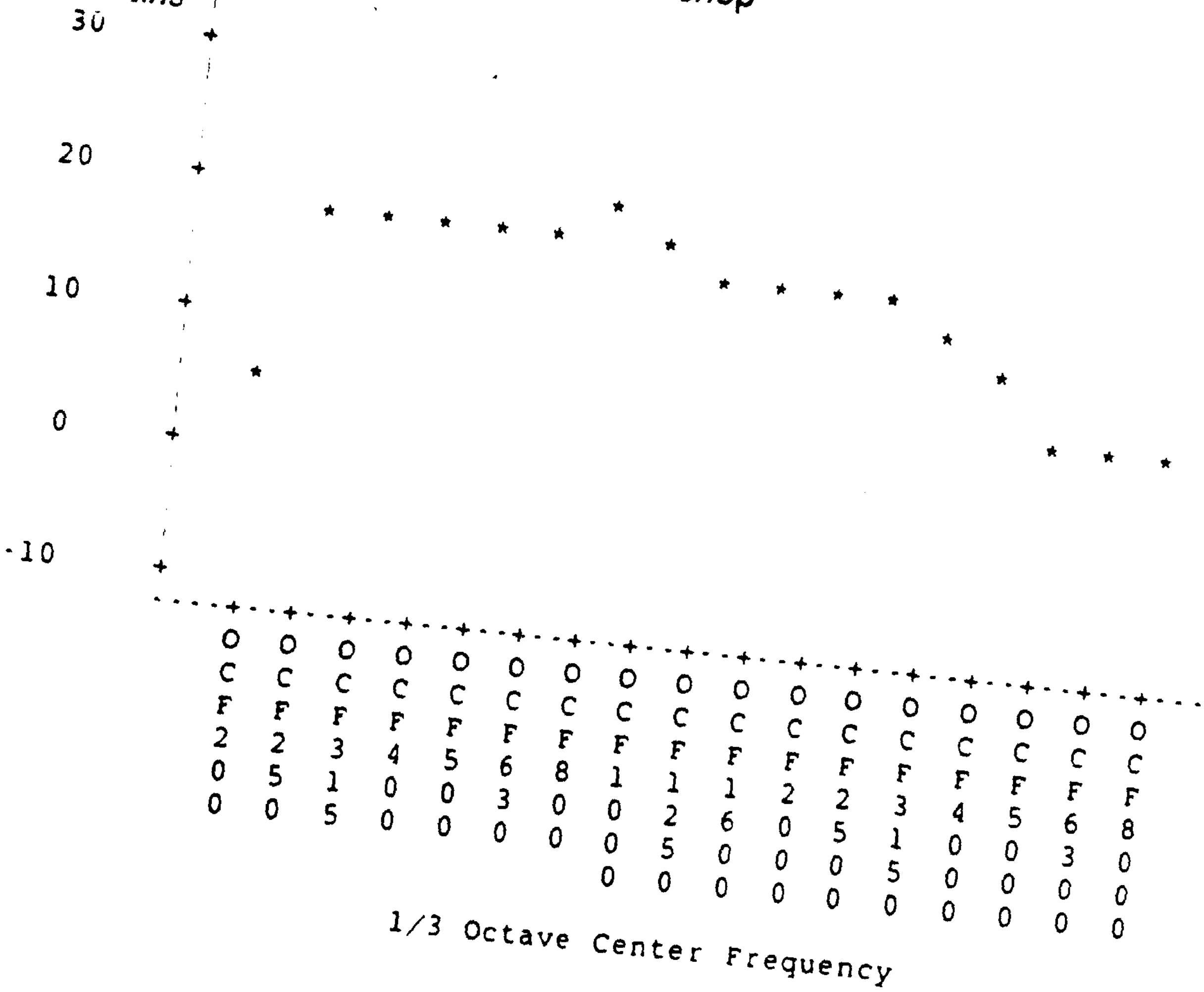
Time (ms)

Wood chop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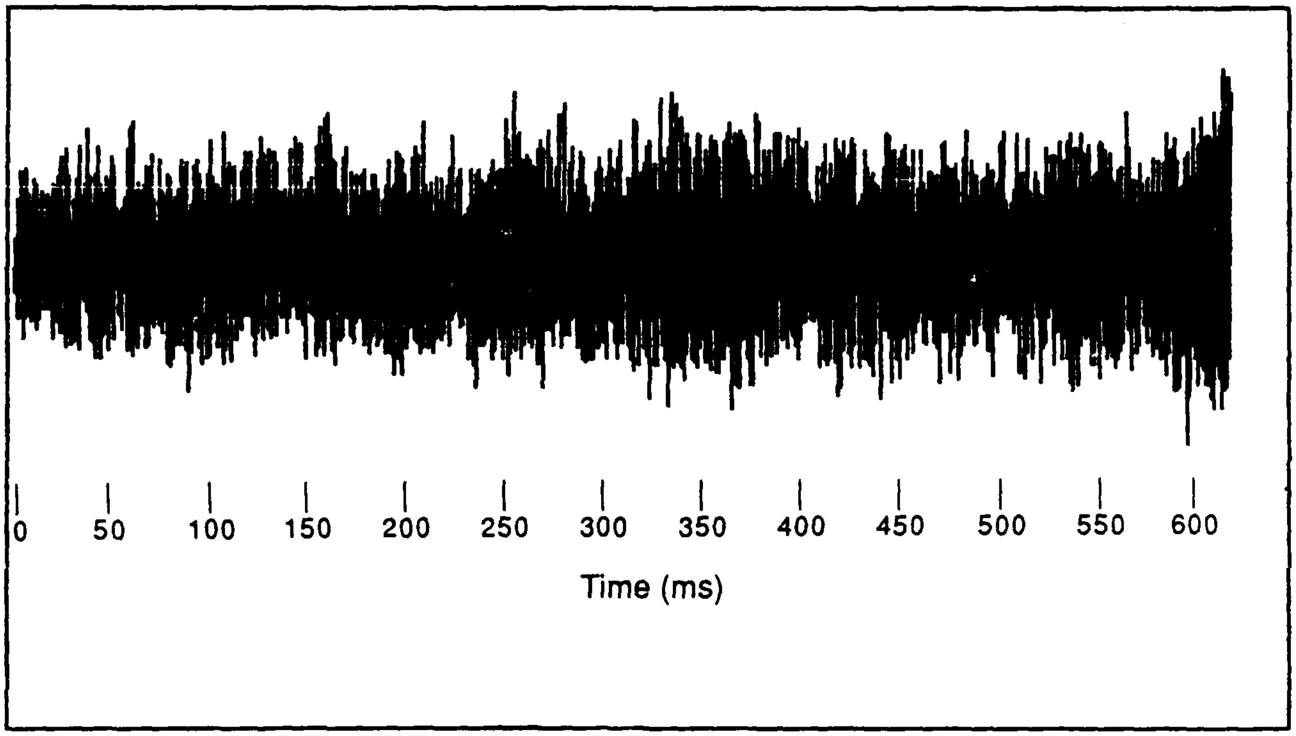
OCF8000
1/3 Octave Center Frequency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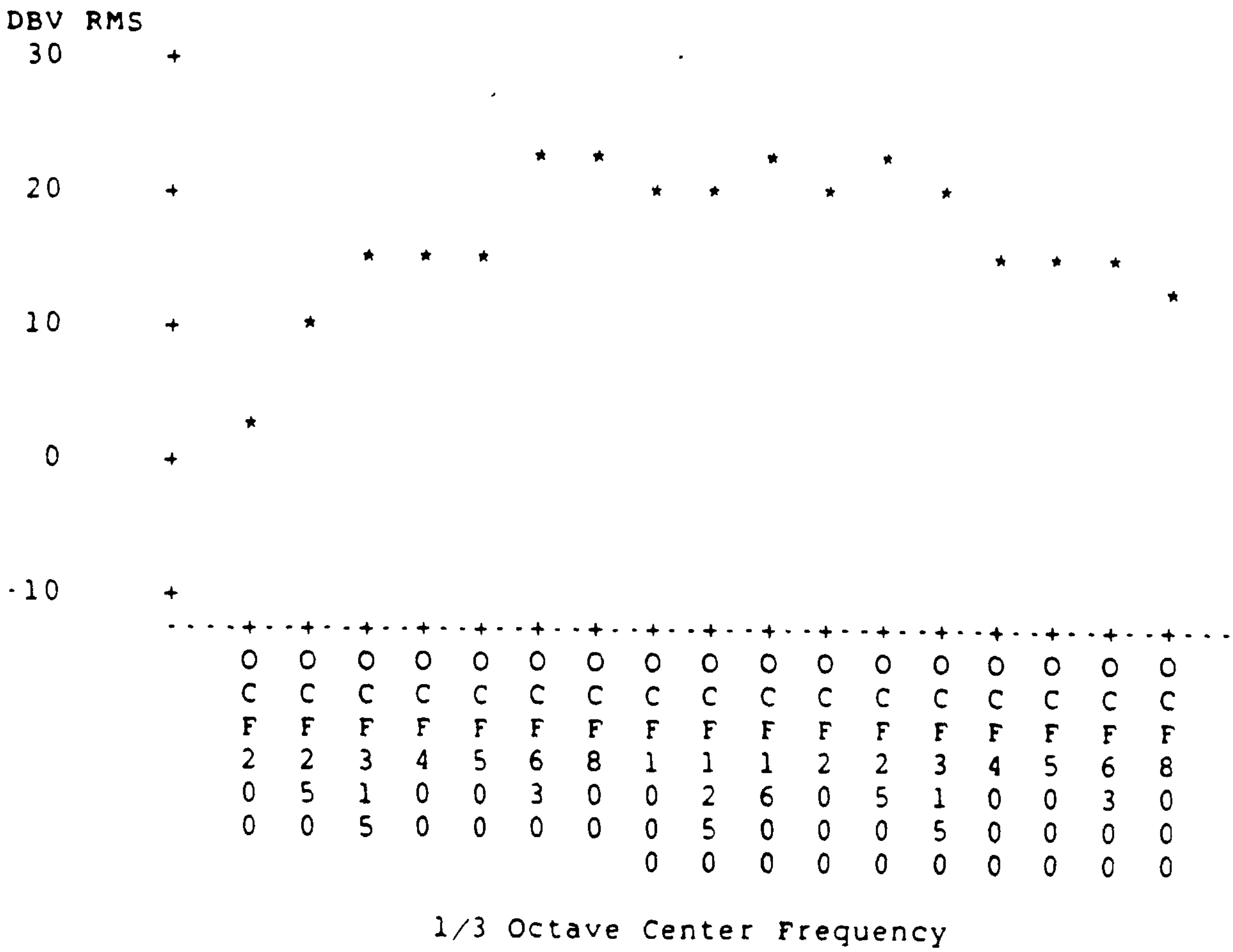
Time (ms)

Power Saw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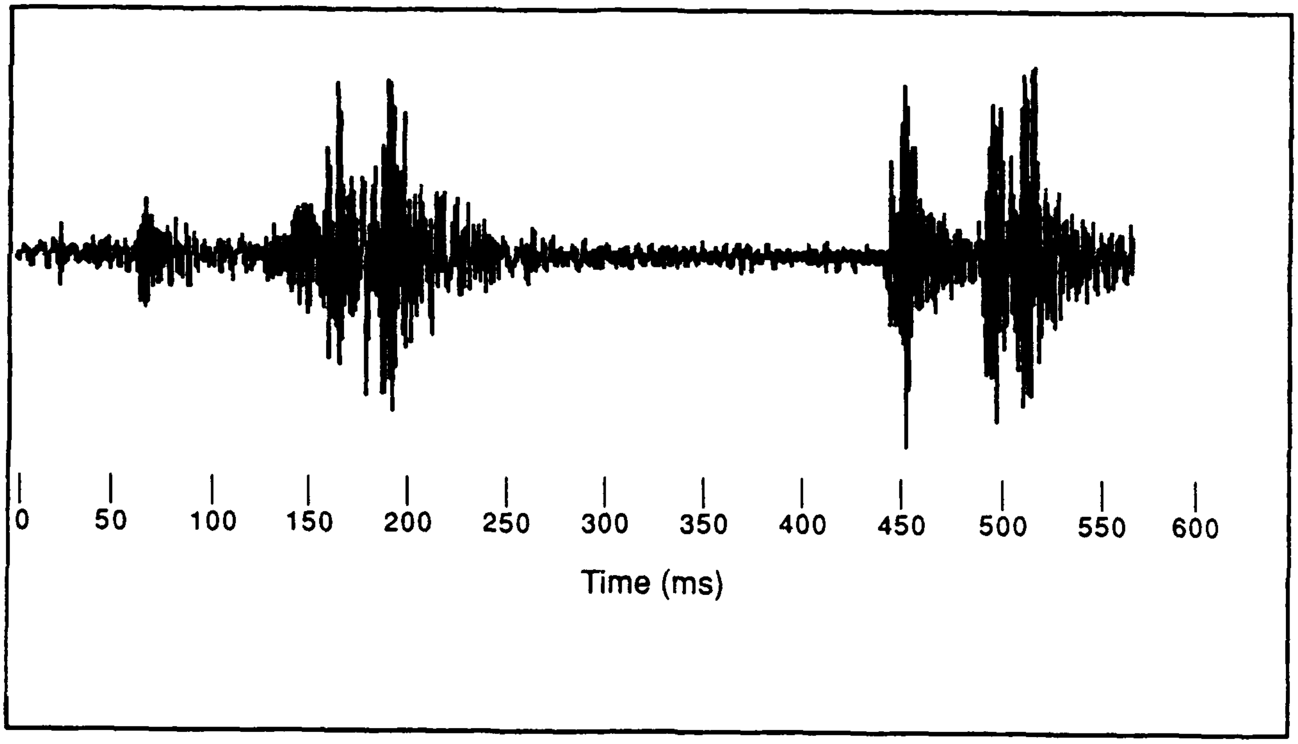
1/3 Octave Center Frequency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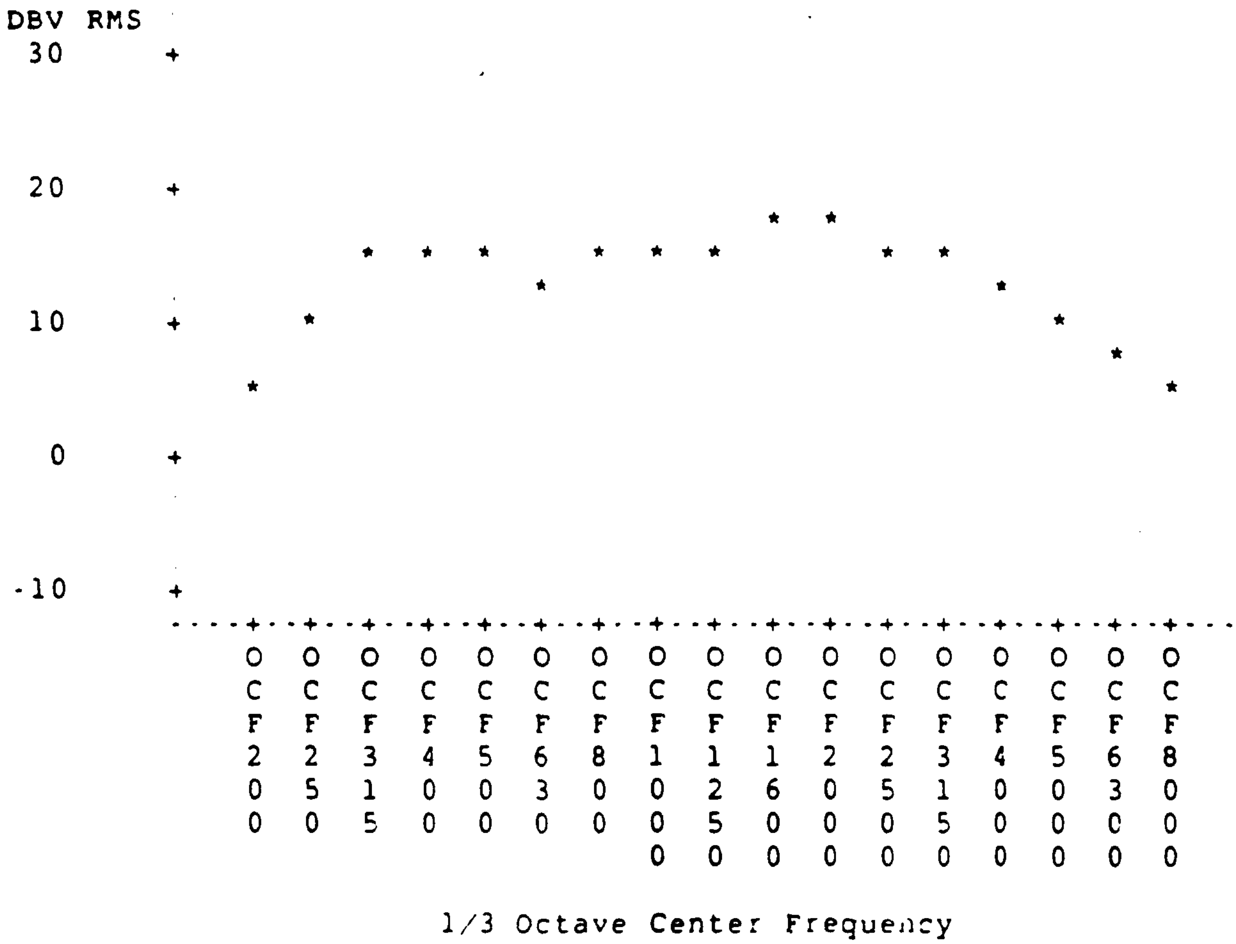
Key in lock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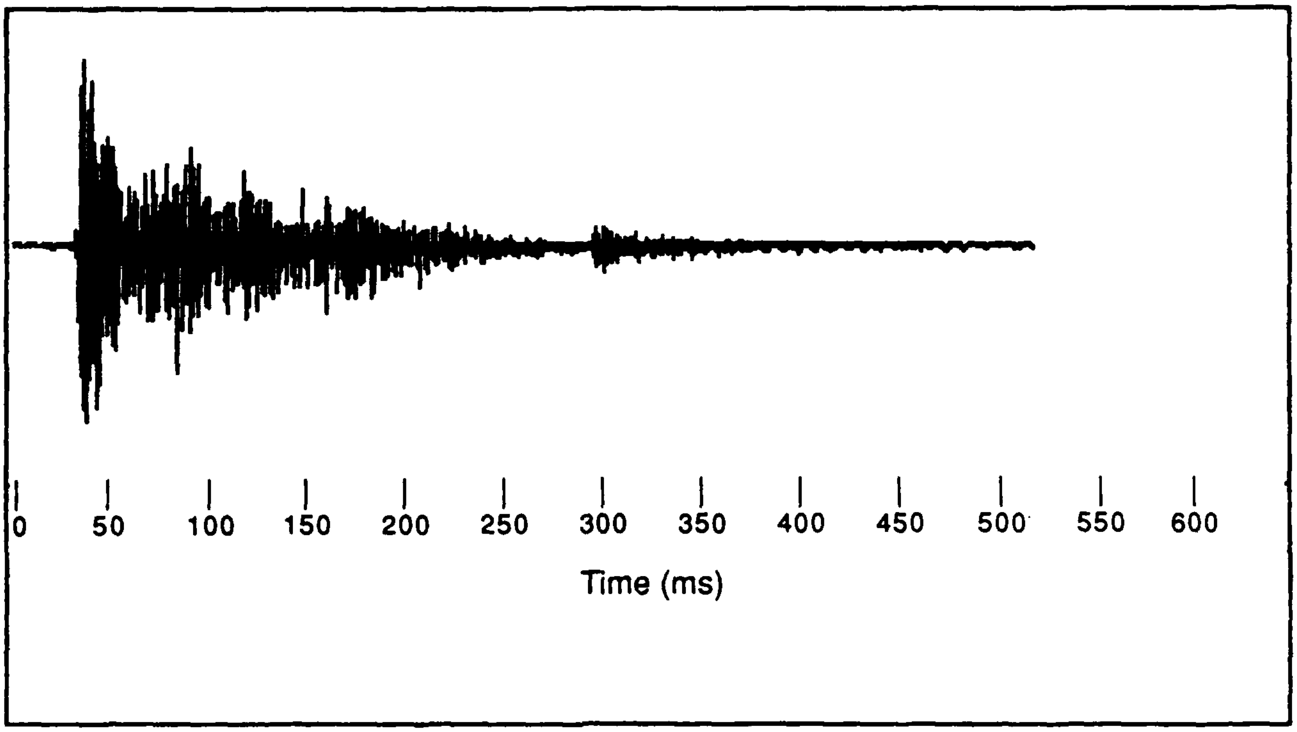
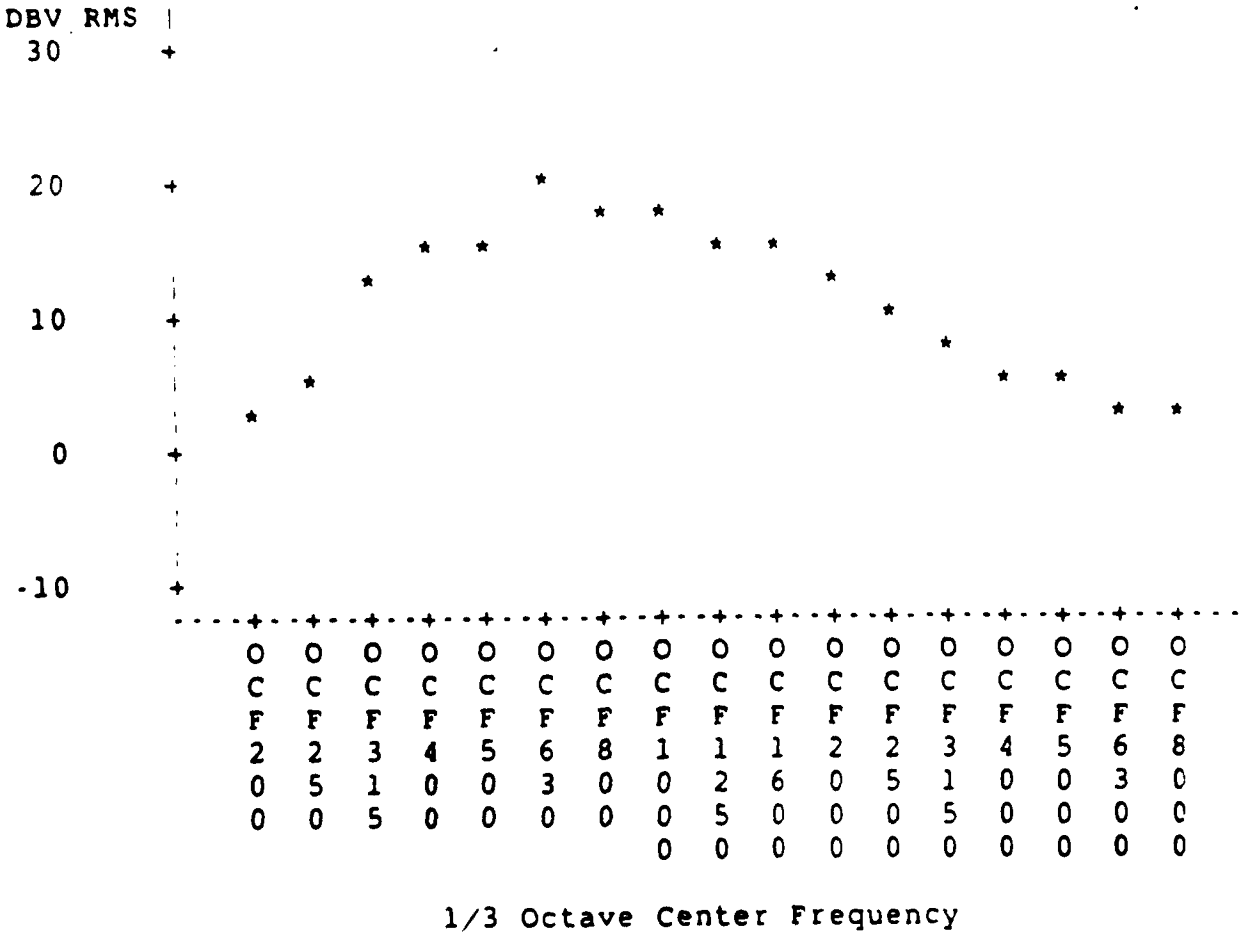
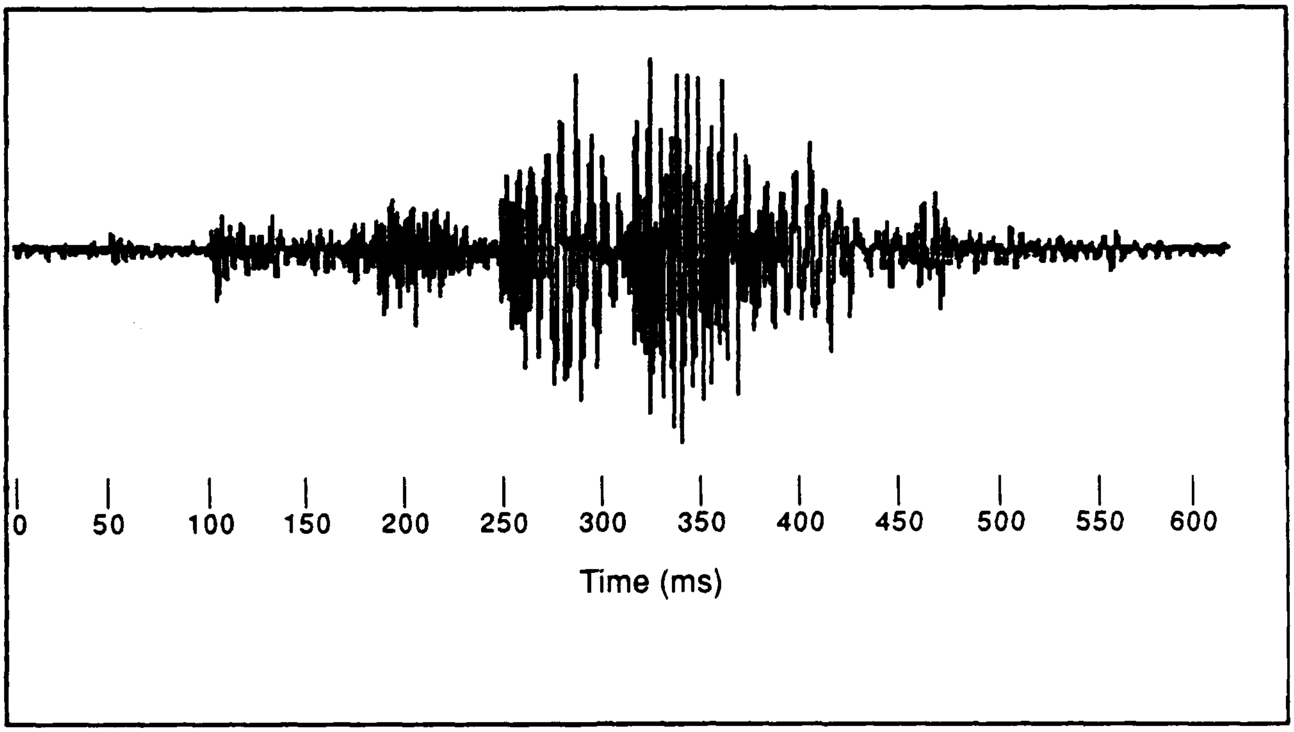
1/3 Octave Center Frequency

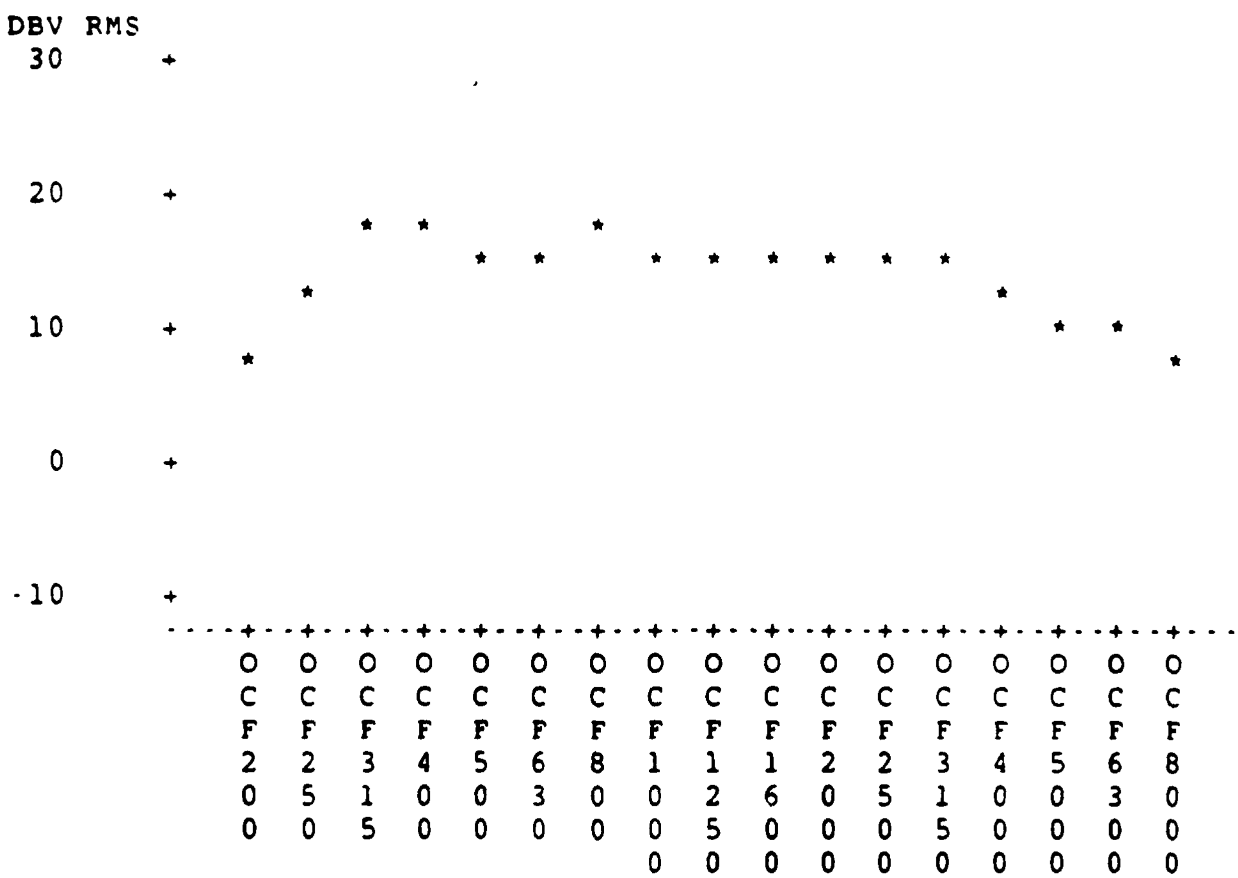


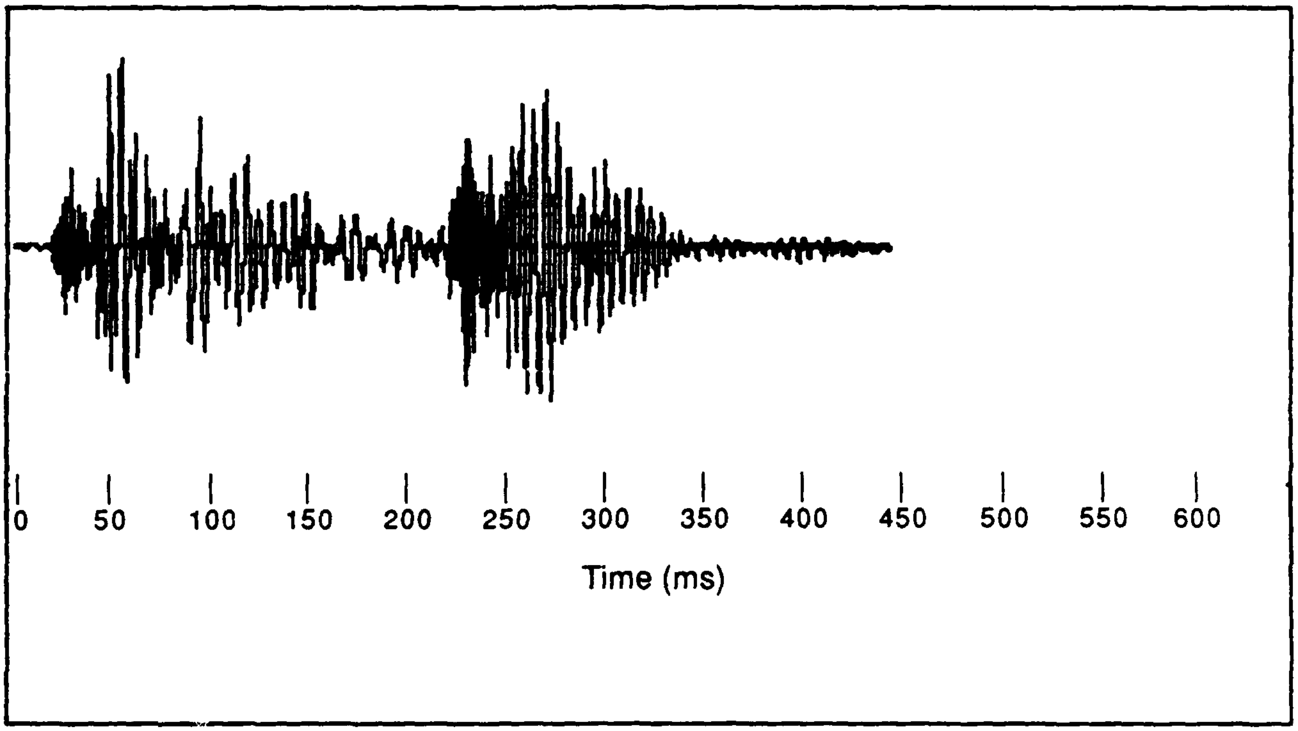
Cork popping



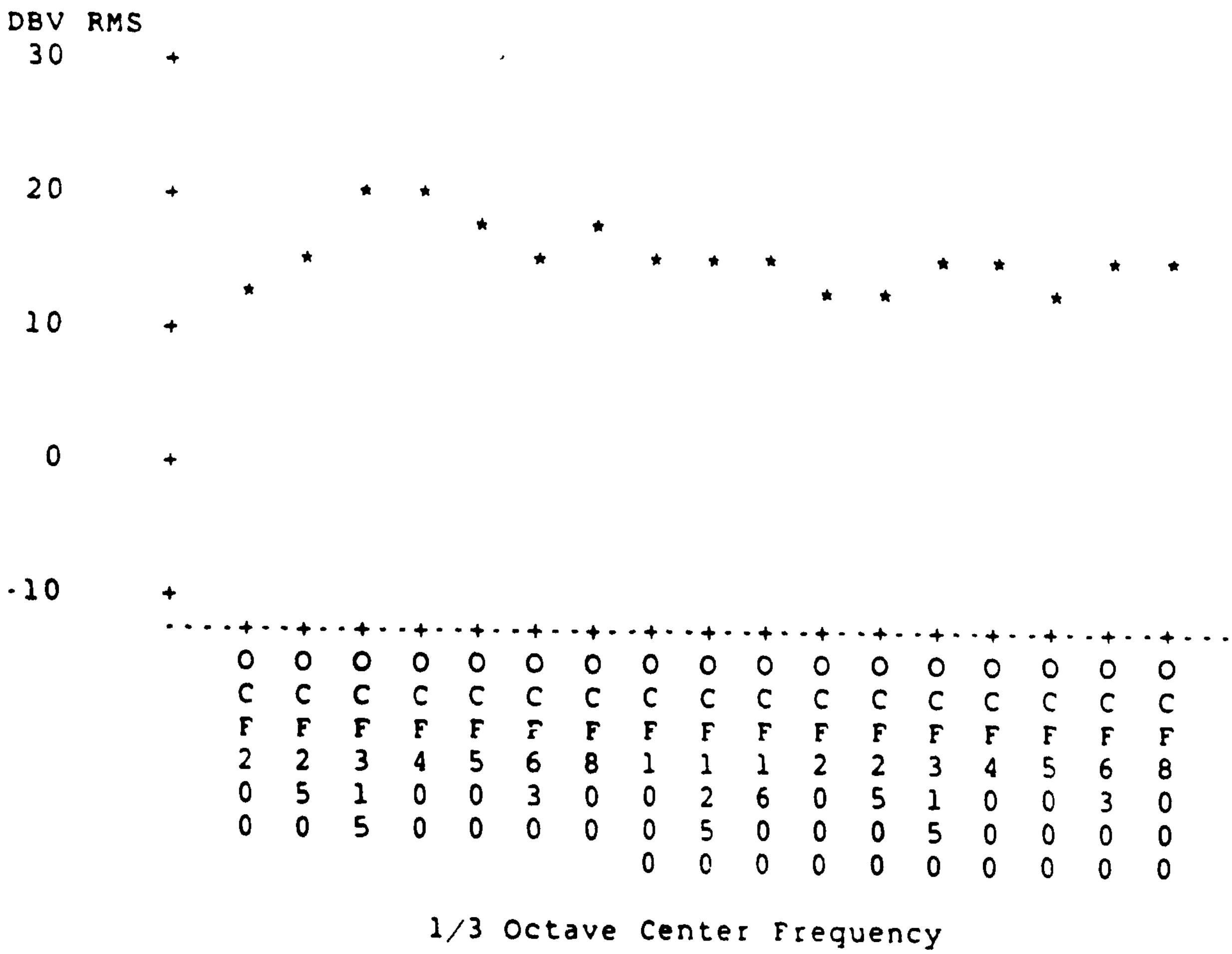


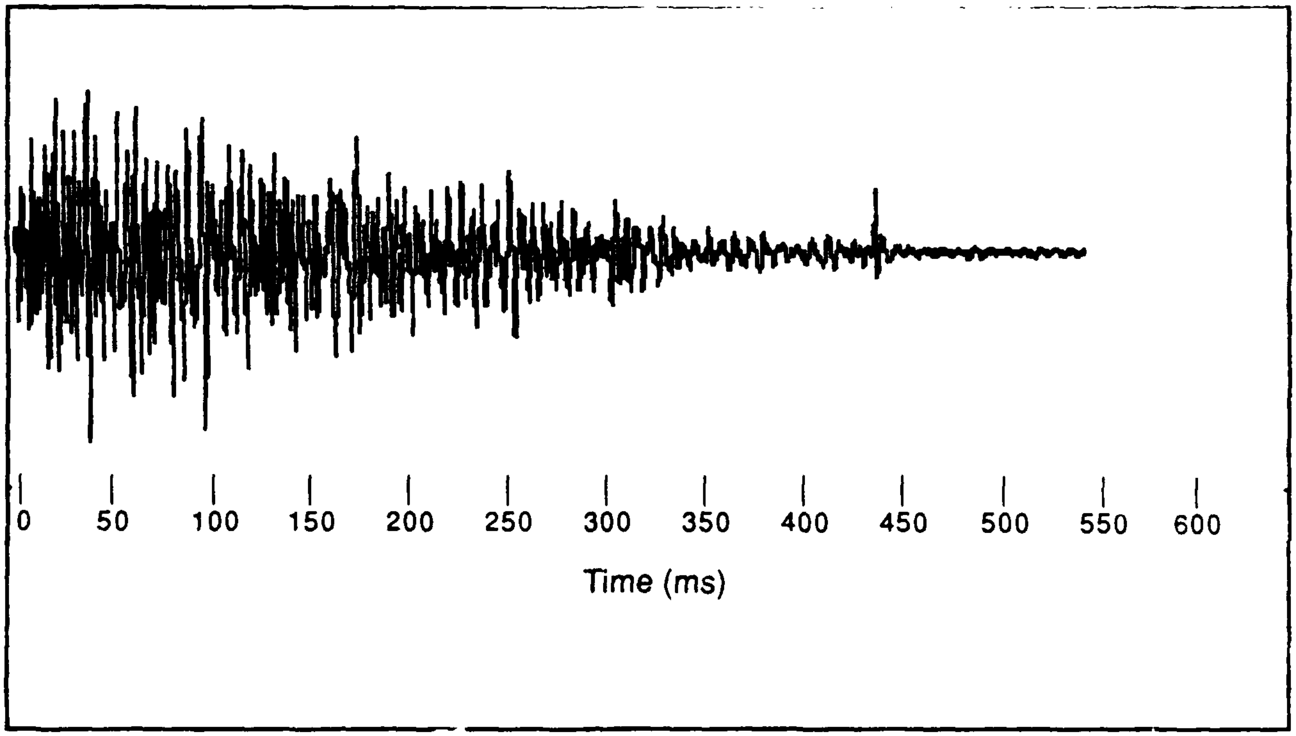
File cabinet door



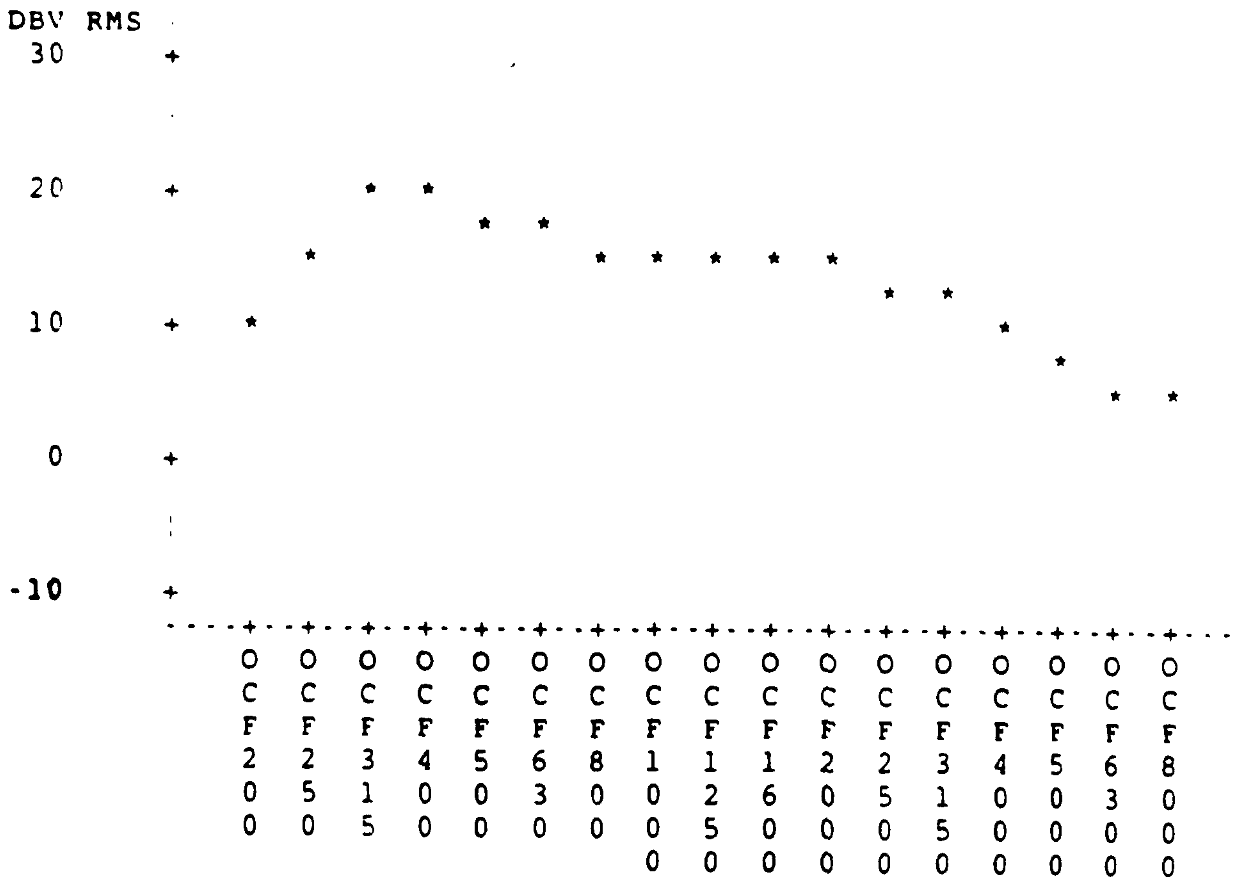


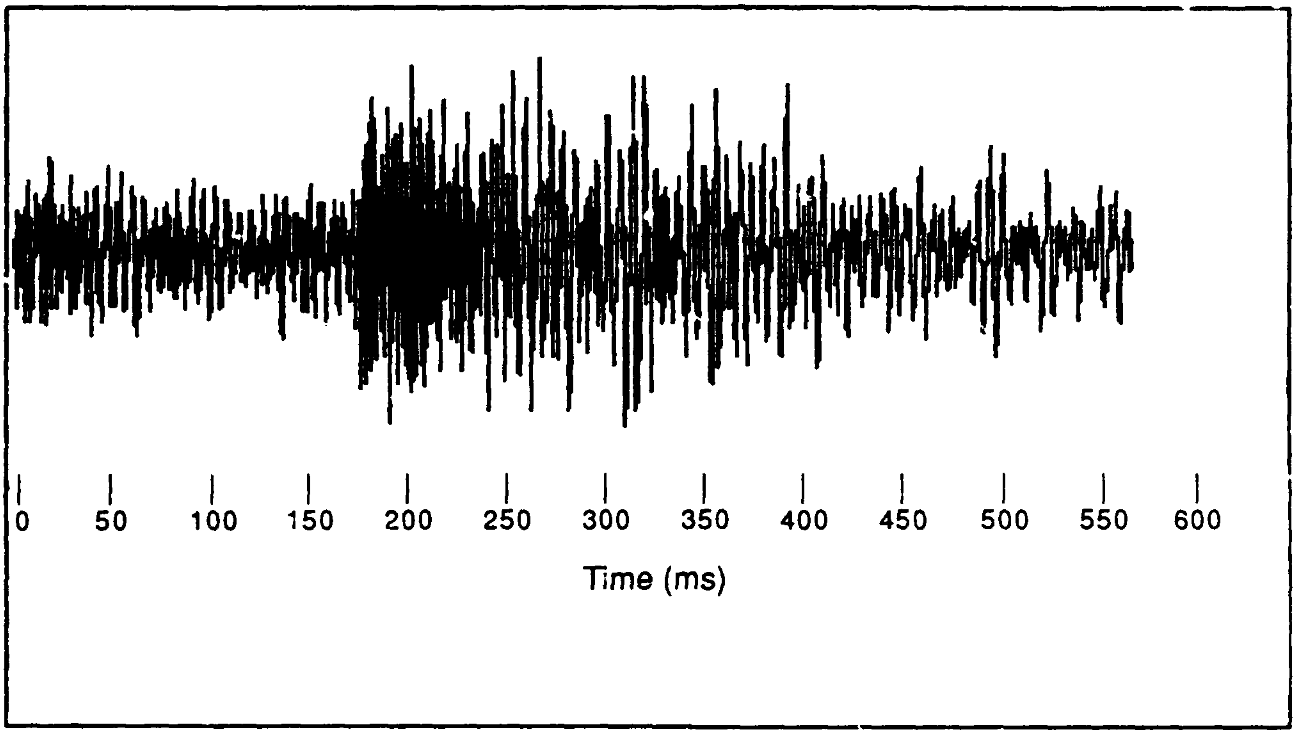
Door closing



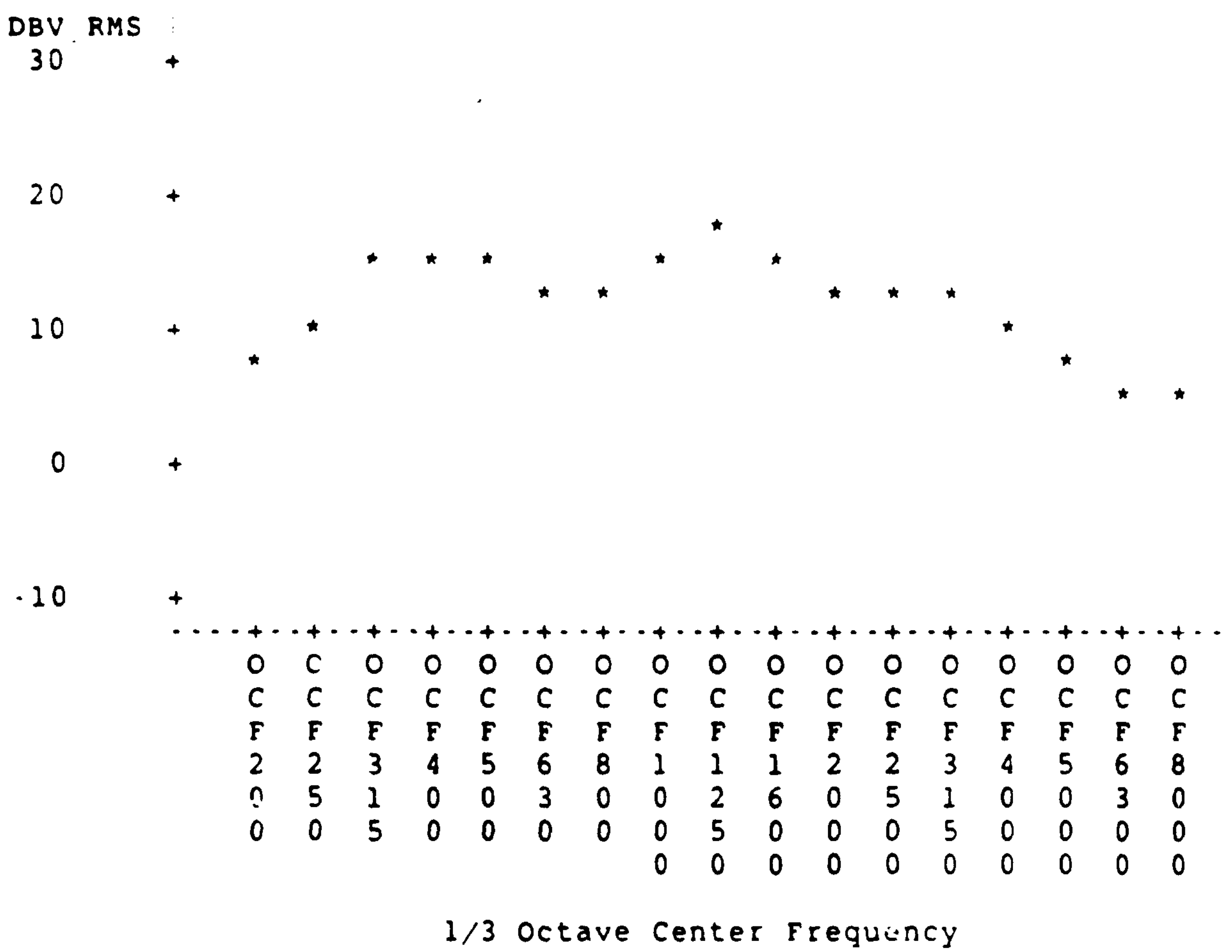


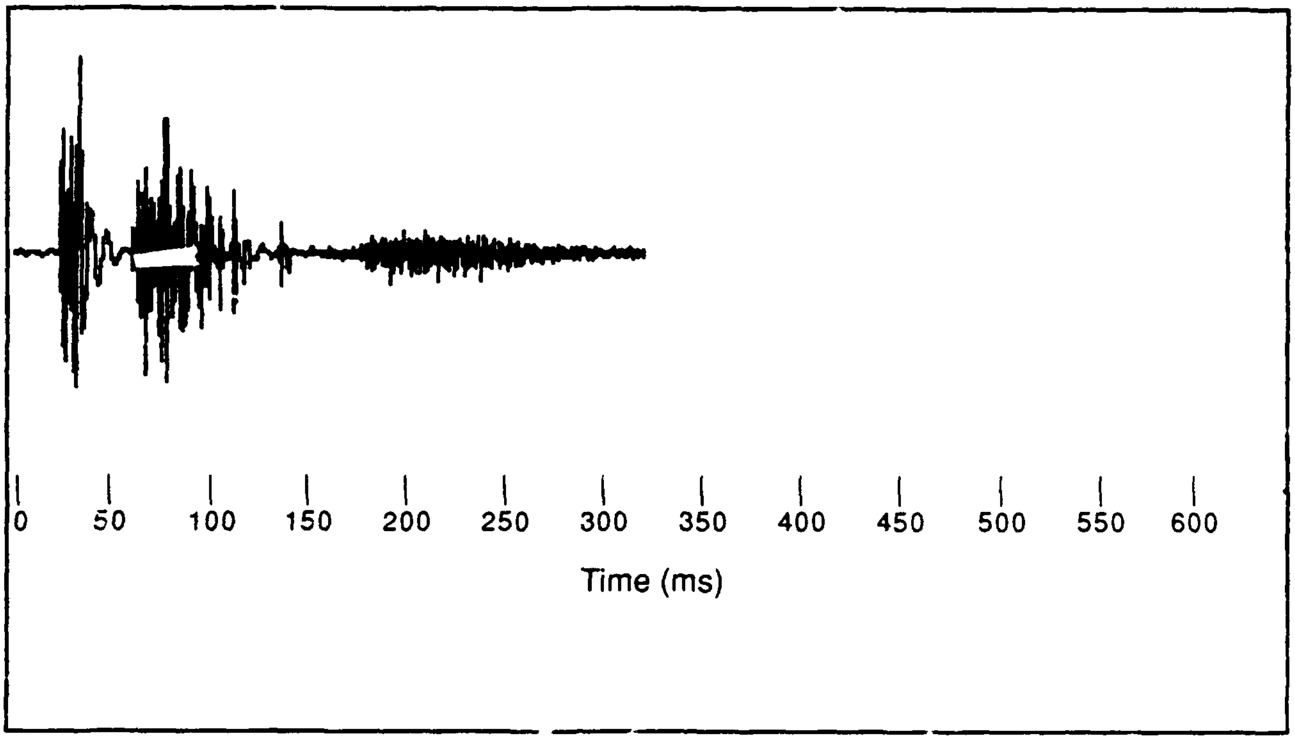
Car backfire



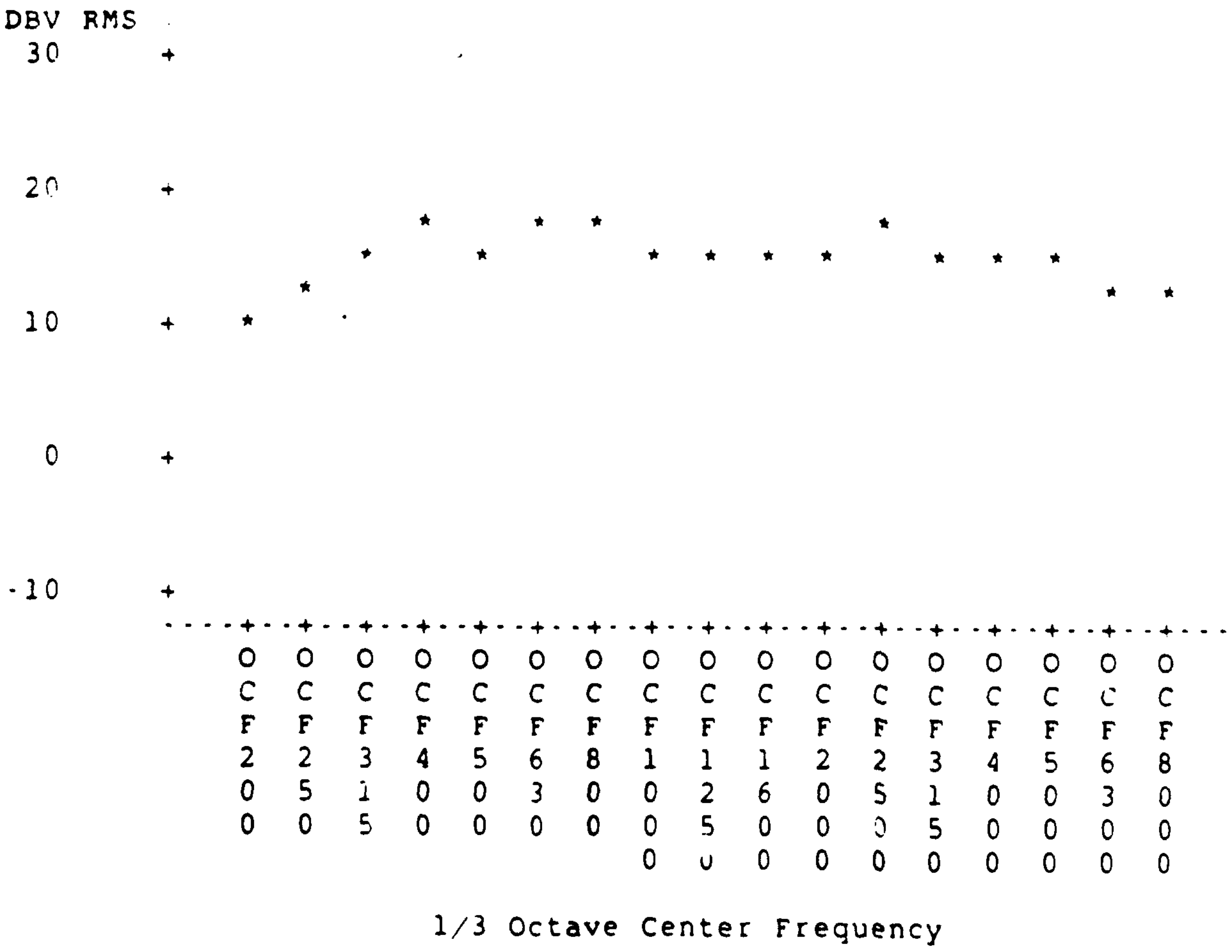


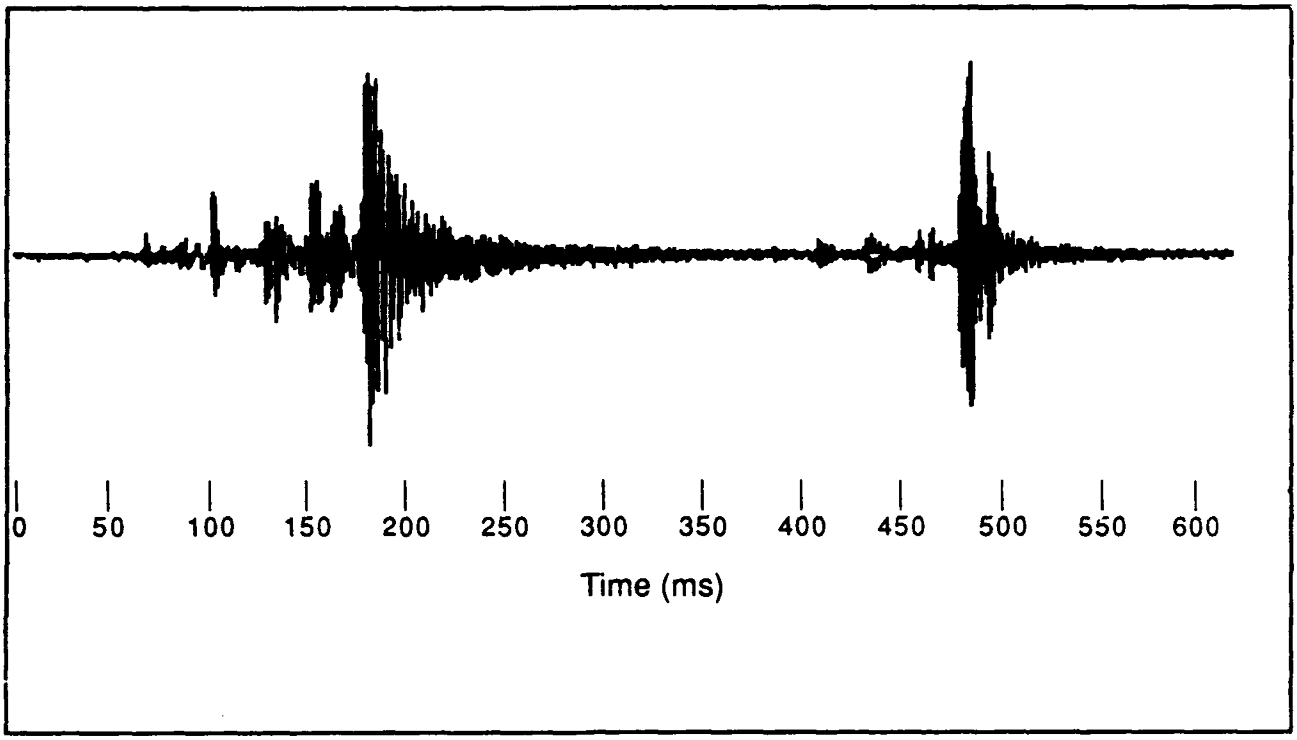
Jail door closing



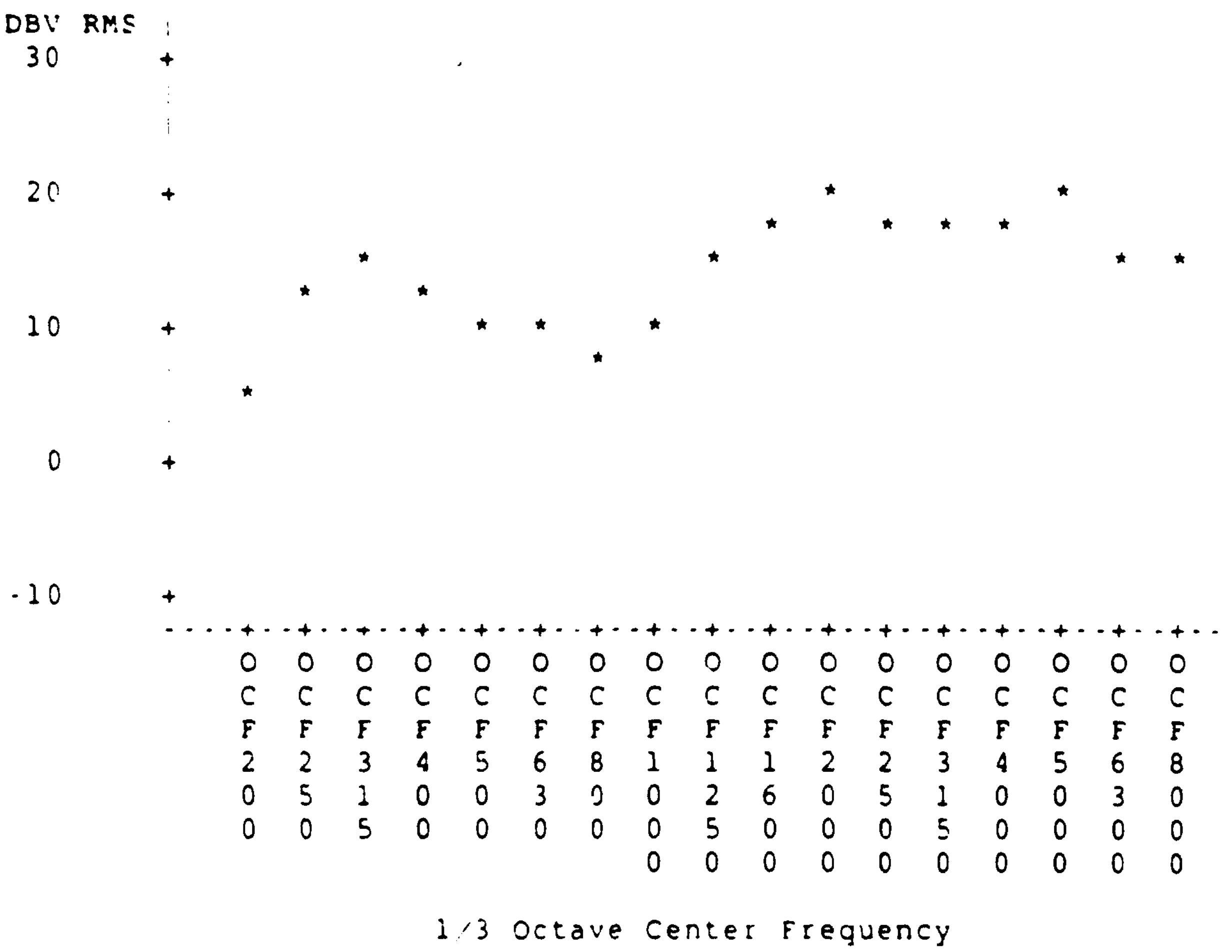


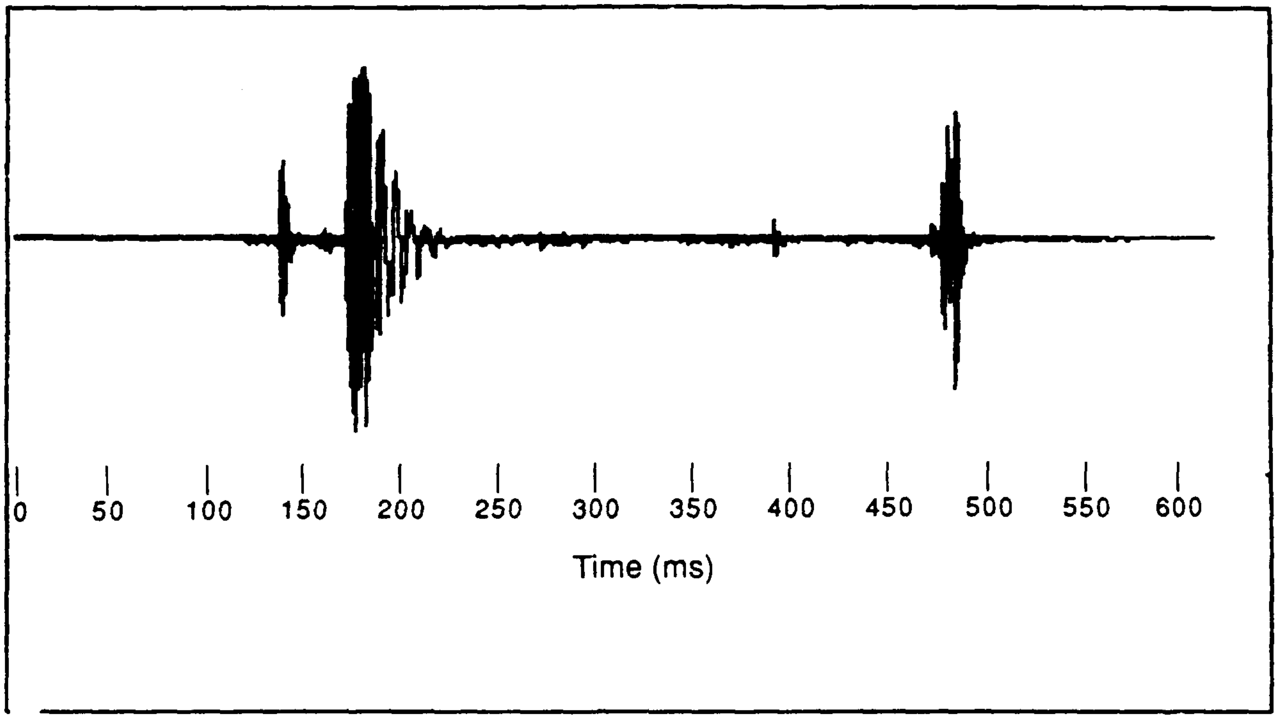
Rifleshot outdoors





Light switch





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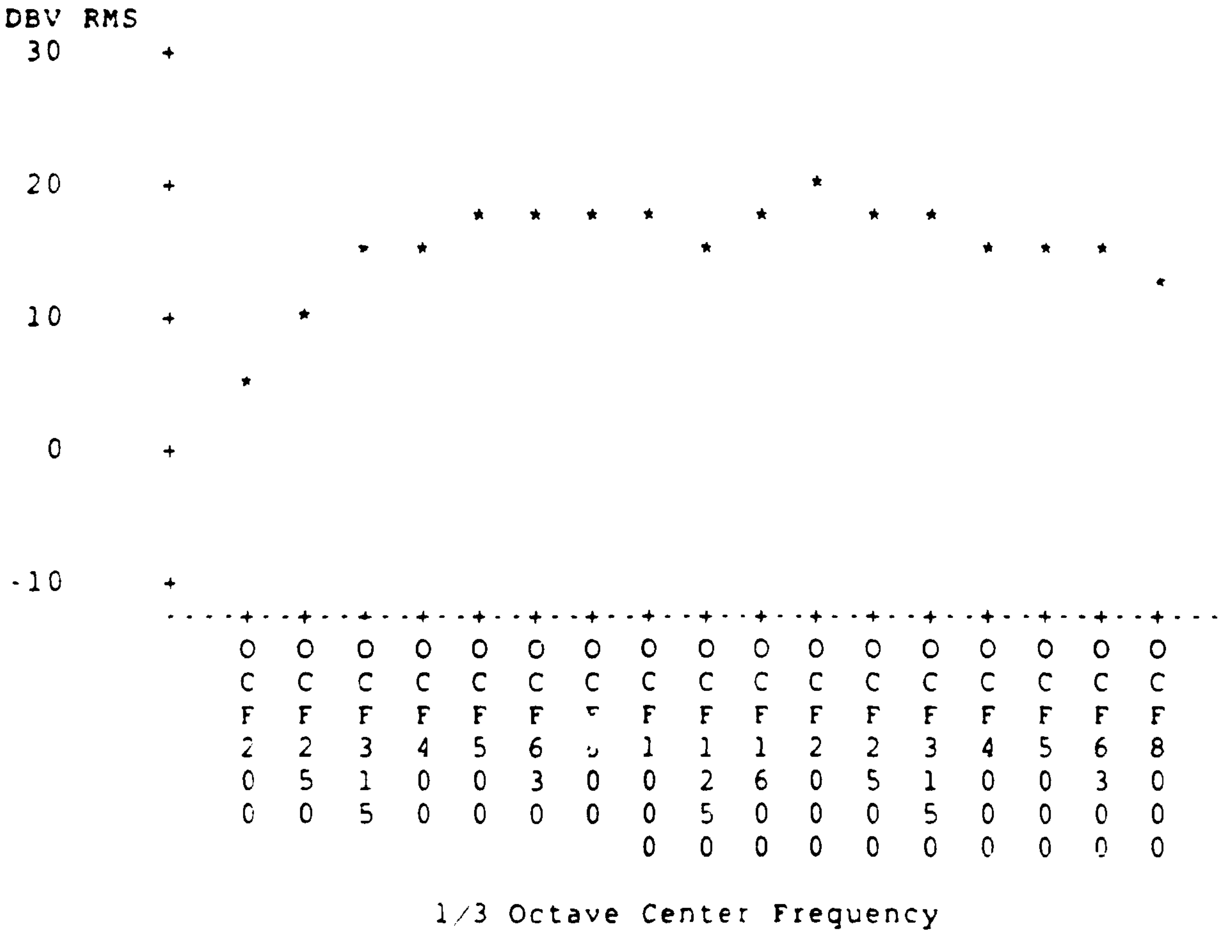
Time (ms)

Stapler



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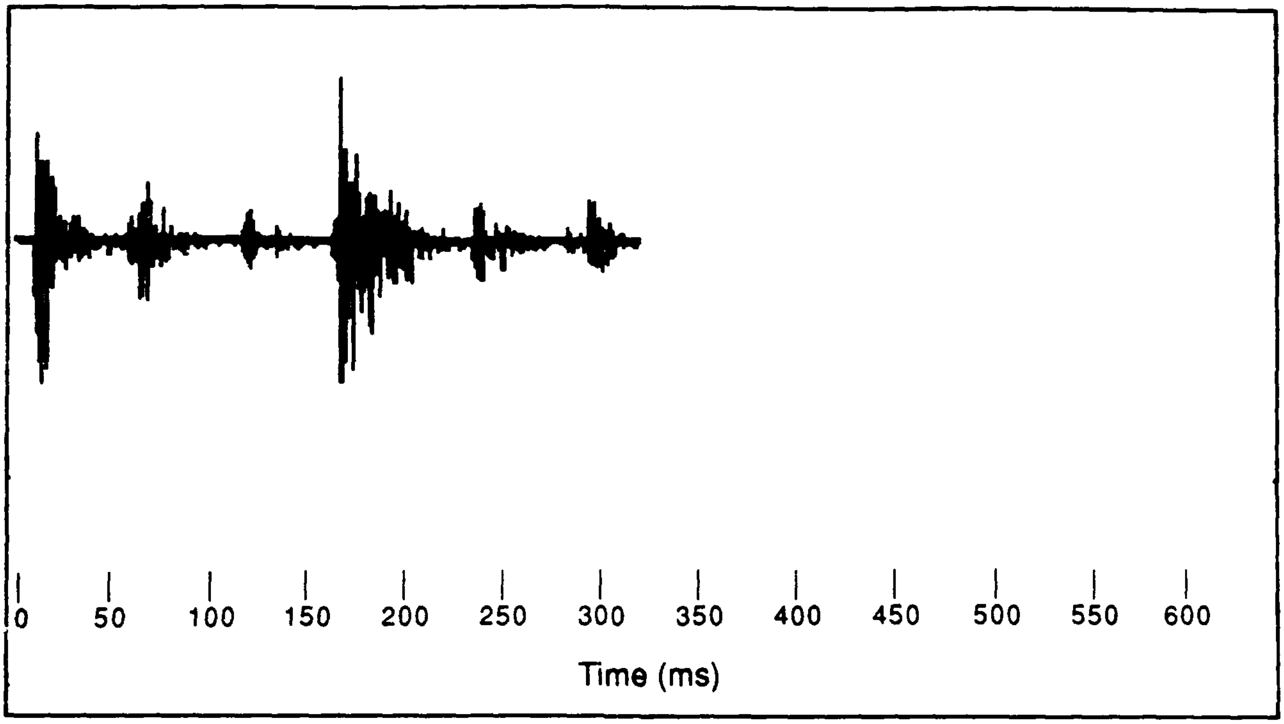
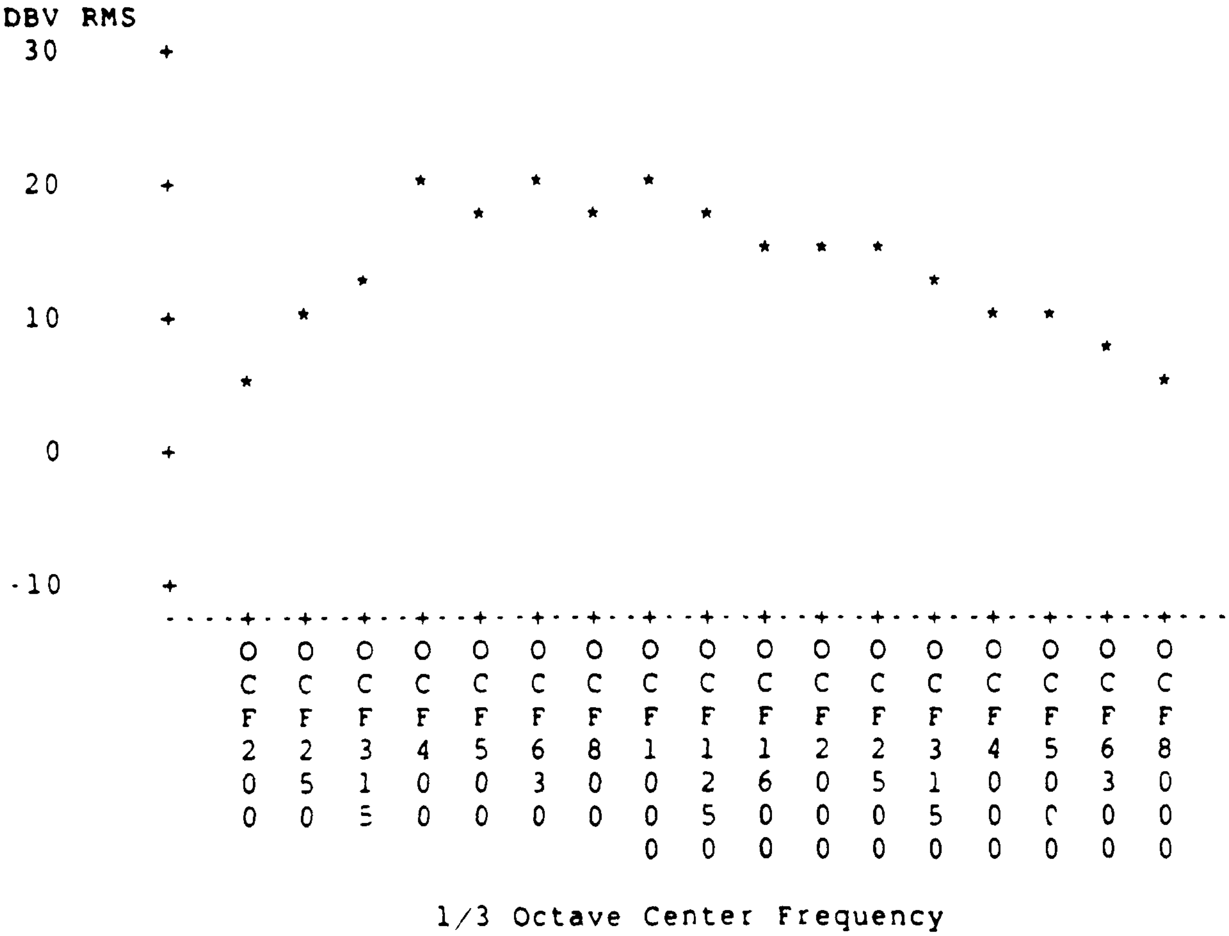
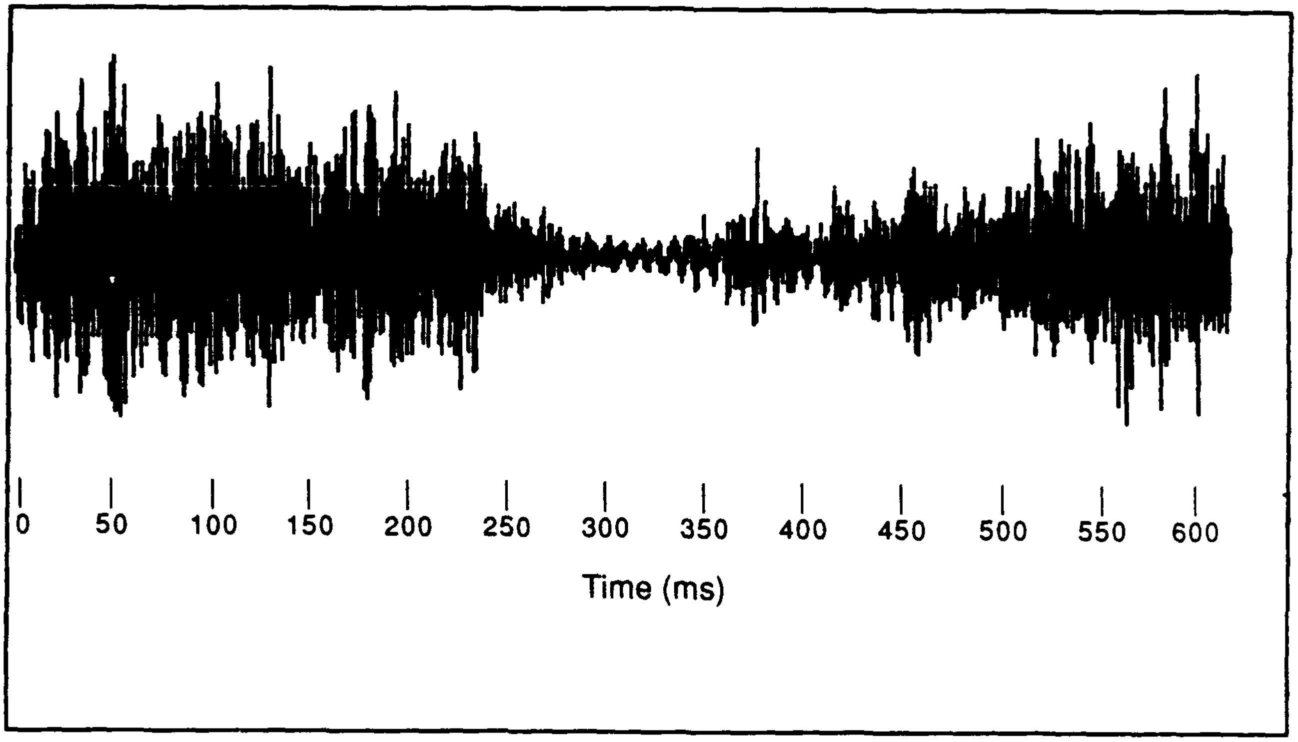
1/3 Octave Center Frequency



Telephone hangup

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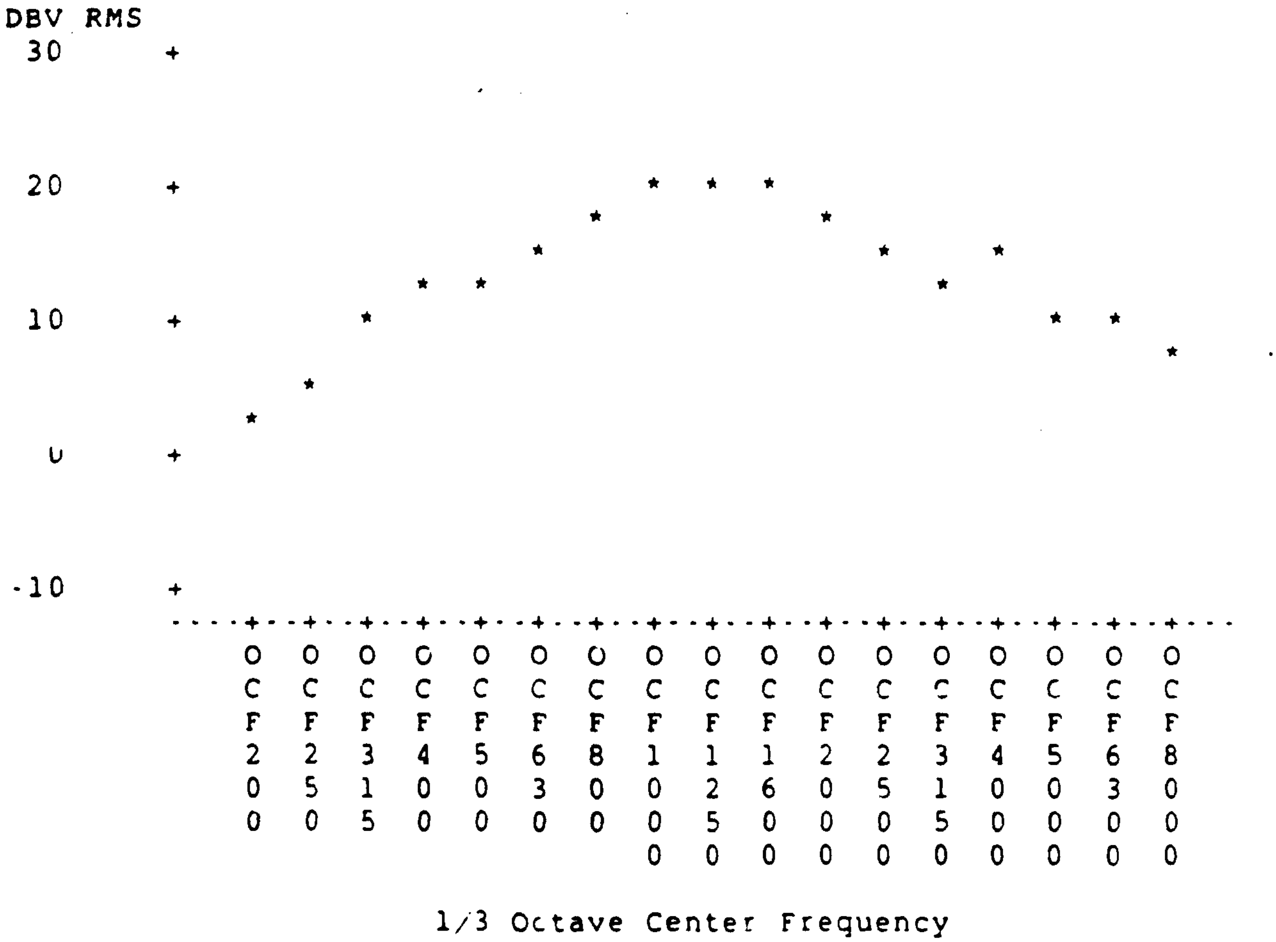
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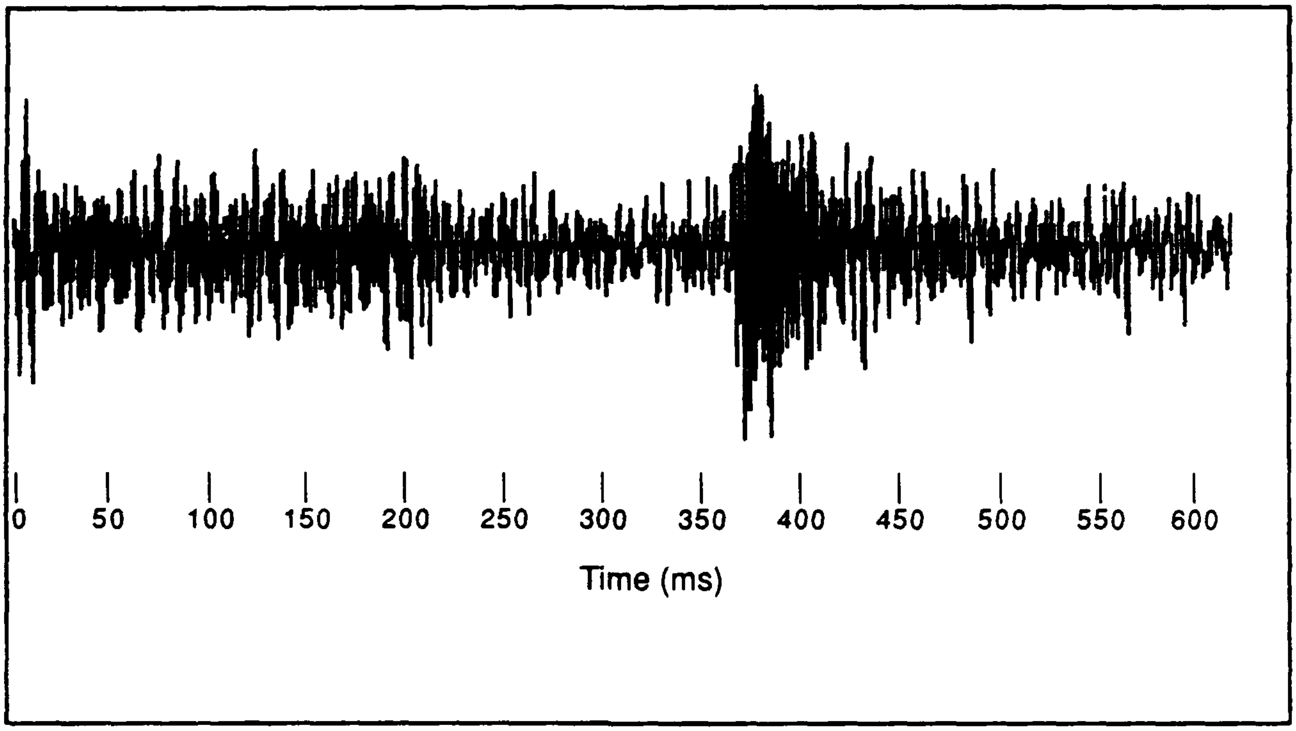
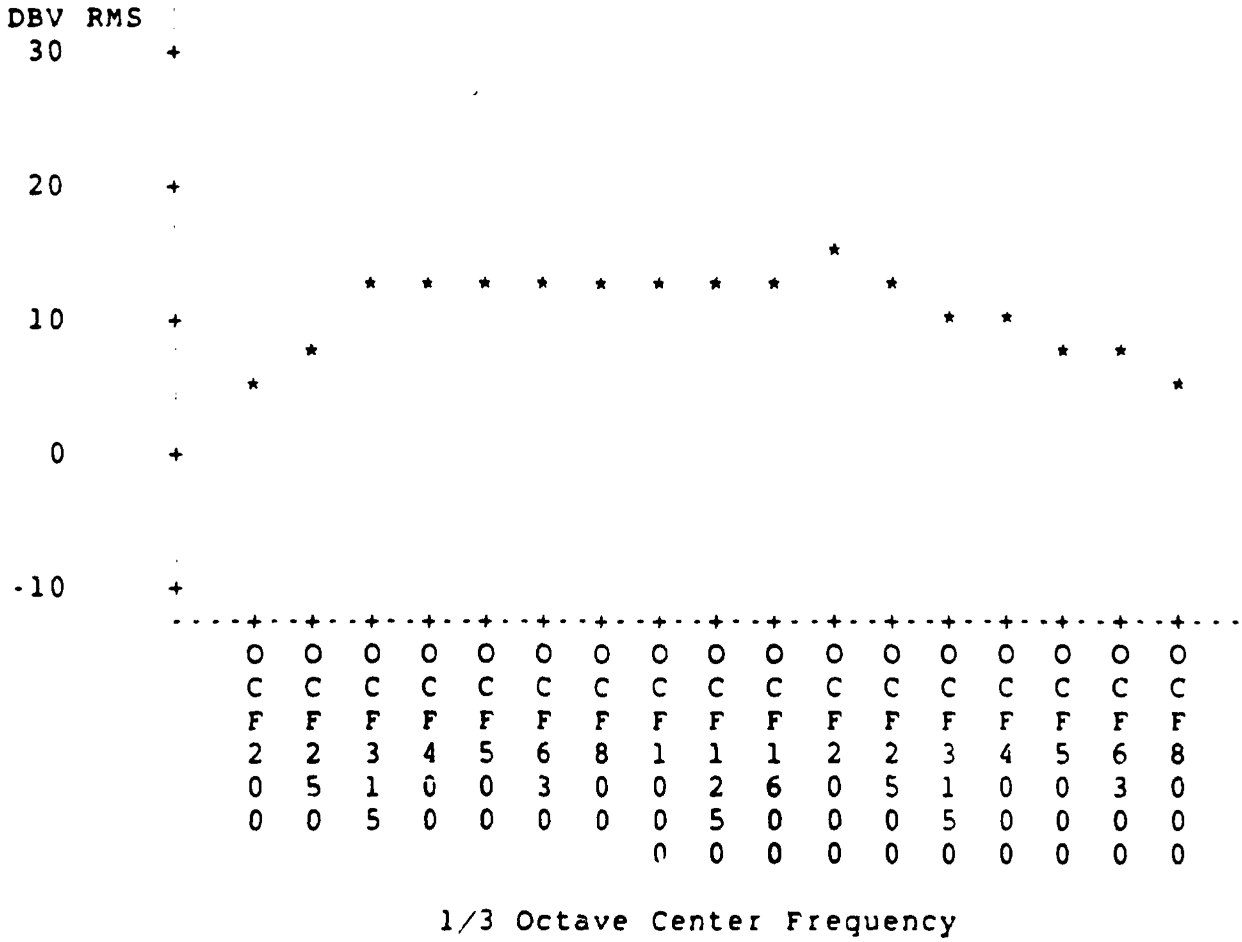


Electric lock



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